FOREWORD

THE FIRST TWENTY-FIVE YEARS

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THE Journal has now been in existence for twenty-five years: perhaps the most fateful twenty-five years for centuries. For they included the Second World War which caused Britain colossal losses both material and cultural, brought revolutionary changes in our social structure, and saw the virtual extinction of the Empire that for a century had given peace and prosperity to a large part of the world. What these changes may portend is not yet clear: pessimists see them as the beginning of the end, optimists as the dawn of a more stable and enduring Commonwealth. In two directions, however, there have been great gains: science and technology have advanced more rapidly than ever before, and are advancing at an accelerating rate; new sciences have appeared opening out vast new fields of knowledge and conferring terrifying powers on a generation that is morally ill-equipped to possess them.

Agricultural science and practical agronomy have advanced with the rest; agricultural and field experiment stations have been established in most countries and, although progress is very uneven, there is now an overall annual increase in world food production of about 3 per cent. compared with an increase in world population of something over 1 per cent. Special interest attaches to the marked development of agricultural research in the colonies and former colonies. In 1934 the senior specialist staffs numbered 180; by 1956 they had increased to 580 without counting the staffs of the four University Colleges with faculties of agriculture founded during the period in Uganda, Nigeria, Ghana, and Ceylon. Since 1940 the British Government has provided £10,500,000 for research out of the Colonial Development and Welfare Funds, and the countries themselves have provided some £5,500,000. Three large research organizations have been set up in West Africa dealing respectively with cocoa, oil palm, and trypanosomiasis; four in East Africa: the Agriculture and Forestry Research Organization, the Veterinary Research Organization, the Institute for Trypanosomiasis, the Desert Locust Survey; the Anti-locust Research Centre; and the Regional Research Centre for the West Indies.

In addition the Colonial Office has established Pools of Plant Pathologists, Entomologists, and Soil Surveyors, the members of which are available for assignments elsewhere.

The large producers' and manufacturers' organizations concerned with colonial products have accomplished considerable advances in many directions. Many of these developments had been foreshadowed twenty-five years ago. The agricultural scientists were first in the field with equipment and organization suited to rapid expansion, including a long-established journal, the *Journal of Agricultural Science*, started in 1905. Application of the scientific results necessarily had to come later. By the 1930's, however, much useful work on these lines was being done throughout the Empire, but there was no single British medium of publication

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such as the scientists had for ensuring the widest dissemination of results of general interest.

The idea of establishing a journal to achieve this purpose is due to the late Sir Frederick Keeble, one of the most brilliant leaders in agricultural science of his time; he also gave the journal its name. An Editorial Board was got together with the writer as Chairman; Imperial Chemical Industries generously made possible the appointment of the late Dr. E. H. Tripp as Secretary and Editor, and the Oxford University Press undertook publication. The first number was issued in March 1933. The Journal at first made little apparent progress; after the third year, however, circulation began to increase and, except for a fall during the war years, it has done so ever since: 1957 had the highest so far, double the pre-war circulation. The number of countries in which the Journal circulates has also increased: 83 per cent. of the issues now go overseas compared with 67 per cent. in the first year. The sources of the papers show a similar outward movement: during the first five years nearly half of them were from Britain, in the last five years only a third; the greatest increase in overseas contributions was from the colonies and former colonies, their share rising from 29 to 43 per cent. of the total—a remarkable tribute to the quality of work accomplished by the able staff attracted to the Colonial Agricultural Service. From the outset it was laid down that papers were not to be automatically accepted for publication; unless sponsored by a recognized authority each is submitted to an independent expert—if necessary to two—to decide whether its quality is sufficiently good.

The subjects have ranged over the whole field of experimental agriculture at home and abroad, but especially in the underdeveloped countries. In every direction there have been great advances, especially in utilizing some of the remarkable products of the unparalleled development of technological organic chemistry since the last war. Chief among these are the selective herbicides: substances which, sprayed at the rate of a few pounds per acre, will spare the crop but kill the weeds, which are the most universal of all crop-destroying agencies. Millions of acres of crops are now treated annually with 2,4-D or MCPA, including large areas of cereals, grass, and other crops in Britain, most of Canada's cereal and other small seed crops, and increasing areas of crops in South and East Africa and Australia. Higher yields are thus obtained, often at less expenditure of labour. It is gratifying to recall that these herbicides were discovered in Britain and are manufactured here, constituting a valuable export commodity. Rapid progress is being made with the discovery of new agents, and it is impossible to forecast the results yet to be achieved.

Technological organic chemistry has provided also a wide range of insecticides and fungicides of greatly improved effectiveness and selectivity: these include synthetic substances, by-products of the oil industry and others. Among recent triumphs have been control, by BHC, of capsids on cacao in West Africa, of sugar-cane hopper in the British West Indies, and of the sugar-cane grub in Queensland;[1] Blister Blight of tea in South India and Ceylon has been controlled by copper

[1] The Queensland growers commemorated this success by a bronze plaque set up at the Meringa Research Station.

sprays; notable success has also been obtained in the control of Black Pod of cacao in Nigeria, with a remarkable response from African cocoa farmers. But it has also been discovered that killing one agent in Nature's great chain of life may upset Nature's equilibrium and thus raise fresh problems as difficult as the original one: repeatedly it has happened that the spray, besides killing the insect intended, has also killed a predator which had been keeping down the numbers of a potential pest: its predator being killed, it can now become really destructive. Systemic pesticides are free from this objection and considerable progress has been made with their use. Seed dressings are also effective and relatively unobjectionable: recent examples are control of Black Arm in cotton in Uganda, Tanganyika, and Kenya by cuprous oxide.

For some pests, largely uncontrolled by present methods, means of containment have been devised. Swollen Shoot of cacao in Ghana is kept within bounds by cutting out diseased trees and preventing contact with other trees. The very interesting disease of cloves in Zanzibar called 'Sudden Death' cannot yet be cured, but much has been learned about it; in any case the disease has greatly declined for no obvious reason, hence, for the moment, the problem has lost some of its urgency; there are also large stocks of cloves in hand.

Pests know no national frontiers, and the great increase in international travel has facilitated their entry into countries where they were never known before. Locusts form a special case in that they have a regular round—smaller now, however, than it was in the past—and by arrangement with the various governments appropriate control measures can be set in operation in the different countries *en route*. Great technical and organizational progress has been made; unfortunately political prejudice has affected operations in one of the chain of countries. In spite of that, however, the severity of the attacks has been much reduced. Considerable progress has been made both in Canada and in India with grasshopper control, which in some years is a matter of great urgency. The writer motored hundreds of miles through Saskatchewan in 1933 when there was a heavy visitation, and saw great areas of ripening wheat absolutely stripped. Driving was difficult because both the windscreen and, unless it was covered, the radiator screen got clogged with the dead bodies, while, in places, the car was apt to skid on the crushed bodies of the masses settling on the road. No remedy was then known: the losses simply had to be endured.

A notable characteristic of the first twenty-five years has been the great extension of joint or team work, resulting in much elimination of the old barriers between one science and another and a consequent exploration of the borderlands between the sciences: 'the seamless robe of knowledge', to quote Whitehead, has become much more than a philosopher's phrase. Plant breeding has been greatly enriched by the co-operation of plant pathologists, chemists, geneticists, cytologists, and others. The progress of wheat breeding in Canada and India is described later in this number (pp. 114 and 123), and papers in earlier volumes have dealt with various stages in the race between the plant breeder and the mutating rust fungus of wheat.

Considerable trouble has been caused by the unexpected distances over which pests can travel. A rust of maize caused by the fungus *Puccinia polysora*, and long known in the United States, got into West Africa where it did much damage till resistant varieties were bred there. Later it got across the continent into Kenya. Steps were at once taken by Dr. Storey and his colleagues to produce resistant varieties and the problem is so far solved that considerable control would become possible if the disease should prove serious. Valuable work is in progress in Trinidad and Jamaica on the breeding of banana varieties resistant to Panama disease.

Progress in land utilization requires a knowledge of the chemical and physical properties of the soils. In the late 1920's a plan for surveying the soil resources of the Colonial Empire was drawn up, but circumstances prevented its execution at the time. Soil and ecological surveys have gradually been carried out, aided in some countries by aerial photography. One of the earliest was a remarkable survey of the Southern Sudan by C. G. T. Morison, J. F. Hope-Simpson, and A. C. Hoyle, while the first soil map of East Africa was made by the late Geoffrey Milne at Amani. C. G. Trapnell made the first extensive ecological survey of Northern Rhodesia and is now working on similar lines in Kenya: East Africa is now one of the best surveyed regions in the continent. Ghana has inherited a good soil survey.

Modern methods of chemical analysis, including the use of the spectrometer, the colorimeter, X-ray analysis, and various rapid but sufficiently accurate devices, and the introduction of semi-automatic analytical procedures, have greatly increased the amount of data that can be collected about the nature and properties of soils. Some dramatic reclamations, extending over many thousands of square miles, have consequently become possible. Infertility over great areas in Australia and New Zealand was traced to deficiencies of certain of the trace elements; when these were supplied the soils at once became productive. The old Ninety Mile Desert in South Australia is a striking example; its name is now changed to Coonalpyn Downs. Along with development of soil analysis has gone a great extension of field experiments and a wider recognition of the necessity for a proper design that allows calculation of the experimental error: a remarkable example was described by the late Frank Crowther in volume 9 of the Journal. The many calculations required for the experiments of the Advisory and other services in Britain are rapidly made by an electronic computer at Rothamsted. The critically designed and frequently elaborate field experiments of the research stations have often failed to carry conviction in peasant countries and considerable numbers of simple tests of fertilizers known to be needed have been made in many countries on the cultivator's own land, notably India, Malaya, Nigeria, Ghana, and Basutoland; further use being encouraged by supplying more of the fertilizer at reduced prices or on credit till the harvest is in. Considerable quantities are now used for ground nuts and yams in Nigeria and also for sugar cane in India, the West Indies, and other countries where it is grown.

In the advanced countries considerable changes in fertilizer practices

have been necessitated by the production of high-yielding varieties of crops which can profitably utilize larger dressings of fertilizer than the older sorts: such include the modern short- and stiff-strawed varieties of cereals in Western Europe, and hybrid corn in the United States. The result of these various developments has been a great increase in consumption of fertilizers far surpassing anything that has gone before. Fertilizers had been in use for about a century by 1946 and after all that time the annual consumption finally reached 2½ million tons of nitrogen and potash respectively and 4 million tons of P_2O_5. But during the next ten years there was a prodigious jump:

	N	P_2O_5	K_2O
		(million tons)	
1946/7	2·40	3·95	2·51
1955/6	6·30	7·30	6·10

The manufacture of fertilizers, including synthetic nitrogen compounds, has greatly increased in Great Britain, Canada, South Africa, and Australia, and a factory has been set up in India.

Considerable use is being made by scientific workers of the isotopes now available from Harwell. Radioactive phosphorus is used for studying the phosphate nutrition of plants, the movements of the phosphorus atoms being recorded by autoradiography. The phosphate interactions of the soil have also been followed and the results may throw light on the low utilization of fertilizer phosphate by plants—at present only about 25 per cent., if as much. Isotopic nitrogen is also being used, but as it is stable and does not disintegrate it is not radioactive; photographic techniques are not practicable and a mass spectrograph is required for its detection and estimation. This type of investigation is still in its infancy, but it promises to open up vast new fields of study.

Over great areas of the Commonwealth crops suffer from lack of water and methods of conserving the store in the soil are under continuous investigation in Canada; the results are discussed on p. 85. One of the most striking improvements in the cultivation of coffee in East Africa has been the practice of mulching started by W. S. Martin and developed by H. C. Pereira, which much reduces loss of soil moisture by evaporation. Where the rainfall is insufficient the water supply is, if practicable, augmented by irrigation and here the combination of engineering and agricultural science has resulted in some remarkable achievements. In two instances—the Snowy River Scheme in Australia and the Big Thompson Project on the Colorado River—rivers have been decapitated, and water unwanted along the natural course has been deflected into a tunnel through the divide and into a river system on the other side of the watershed where it was badly needed for irrigation. In India the Damodar valley is being developed in a comprehensive scheme involving water storage, irrigation, electric-power supply, anti-erosion works, and reclamation of great areas in the head-water region, while the utilization of the waters of the Indo-Gangetic river system has been carried a stage further by the erection of the immense Bhakra dam.

On the smaller scale, but of great local importance, have been the

schemes for drainage and reclamation in the Shire valley in Nyasaland, and of the Mangrove soils of Sierra Leone that are now growing rice, and the rice scheme of British Guiana; and although it does not fall within our purview, mention must be made of the completion of a further stage of the drainage of the old Zuyder Zee, the greatest reclamation of its kind in the world.

A large amount of work has been done on field crops, especially in the underdeveloped countries on plantation crops intended for sale. These are commonly the chief source of their national income; the whole purpose of their production must therefore fail unless the price obtained is adequate; both quantity and quality must be satisfactory. There is the further advantage that plantation crops usually require the direct participation of resident British experts who thus acquire a far more intimate knowledge of local soil and crop requirements than is possible for any visiting scientist. The remarkable development of agriculture in Kenya and Southern Rhodesia is striking evidence of the advantage of a resident population of British agriculturists. So important are the cash crops that special research stations have been set up to deal with their problems: for cacao in Ghana, coconuts in Ceylon, coffee in Kenya and Tanganyika, cotton in Uganda, palm oil in Nigeria (see p. 136), sisal in Kenya and Tanganyika, sugar-cane in Barbados, Jamaica, Queensland, South Africa, Mauritius, and Madras, tea in Assam, Ceylon, Nyasaland, and Kenya, tobacco in Southern Rhodesia, rubber in Malaya and Ceylon. As a result of these investigations methods of cultivation and of preparation of the produce for market have been greatly improved. The cotton and rubber stations and the West African Oil Palm Research station have established their own journals to which most of their papers are now deflected.

In the past the plantation crops tended to concentrate in special countries which thereby obtained almost a monopoly. So long as there was unified control this system had the advantages of ensuring uniformity of produce and of giving the maximum financial return to the country concerned. In modern conditions this segregation would be unsafe and efforts are now being made to widen the sources of supply; this necessitates the discovery or the creation of varieties well suited to the new conditions. Considerable success has already been achieved with cotton and with tea; and there is much promise for cacao in Trinidad as the result of work by E. E. Cheesman and by H. Evans on the vegetative propagation of clones.

Considerable progress has been made with the improvement of native food crops in the underdeveloped countries, the general object being to increase yielding capacity and to improve resistance to disease and other unfavourable conditions. FAO has set up an inter-Asian research station for rice at Cuttack in India. Cassava, one of the most popular foods in tropical Africa, is unfortunately liable to a virus disease against which nothing could be done till H. H. Storey found an allied plant resistant to it and bred a whole series of resistant varieties. The millets for long were unrewarding because native selection over many years had already weeded out unsuitable sorts; better results are now, however, being obtained. Yams also have been studied.

Perhaps the most striking advances have been in the methods of managing grassland, and practically all the Commonwealth countries, and especially New Zealand (see p. 152), have participated. In Africa the native herdsmen had alternately grazed and burned the herbage, which gradually eliminated the useful plants and depleted the vegetation cover, so that erosion became more and more serious. Remedial and preventive methods fall into two groups: ecological, in which grazing is strictly controlled, and the pasture management so designed that the valuable plants among the native flora are encouraged and the weeds depressed; and the replanting method, in which the land is broken up and sown or planted with selected good grass from other regions and is then treated with fertilizer to ensure full growth; this involves extensive search for promising sorts and their cultivation in small plots. Useful work is being done at the Grassland Research Station, Kitale, Kenya. Search is still proceeding for the most suitable legumes to accompany the grasses; in several cases these still have to be found. In the United Kingdom still more intensive methods have been worked out at Hurley, Jealott's Hill, and elsewhere, some of which have been described in the Journal, full use being made of the improved strains produced at Aberystwyth.

The livestock problems dealt with in the Journal have been largely concerned with breeds and crosses, with foods and feeding, and management. The problems are less important in Asia than in Africa, the higher density of human population on the land allowing little space for animals; notwithstanding this, however, India has the largest cattle population in the world, not because it is really needed but because religious scruples forbid slaughter. In Africa livestock are extremely important, especially in the more arid regions; for large numbers of the population they are the main means of livelihood, there being in the mining districts a large but not exacting demand for meat. Difficulties arise in districts where livestock constitute the wealth, the bride-price, and the mark of social distinction: in that case numbers alone count and little interest attaches to possibilities of beef or milk production. Markets have, however, been established, and hard cash is beginning to make its appeal. Over large areas diseases are very rife: indeed in the very wet regions insects carrying diseases are so prevalent as to prevent the survival of any except a few highly resistant breeds. Much progress has been made in control of infectious diseases. Rinderpest and Pleuropneumonia are well in hand, and Redwater and East Coast Fever are being reduced by dealing with their carriers, the ticks. As with human beings, however, the control of disease has greatly increased the population and has thus created far-reaching food problems: unless the pastures are adequately improved so as to provide the necessary additional food the animals will suffer from undernourishment and the herbage will be overgrazed, leading to serious soil erosion: overgrazing is indeed one of the chief causes of erosion at the present time. On the other hand, where pasture improvement has kept pace with disease control both animals and soils have benefited. With better food supplies it has become possible to improve the breeds, and search is still continuing

for crosses suitable for different conditions. Increasing use is being made of artificial insemination in Kenya, Nigeria, Jamaica, Mauritius, and India, using techniques developed in Britain. Valuable results are being obtained by British farmers in Kenya.

Native agriculture in many underdeveloped countries suffer from fragmentation and scattering of the holdings. Marked progress has been made in Kenya in consolidation and planning, and notable benefits have been demonstrated. These results are likely to have far-reaching effects throughout Africa.

In the advanced countries immense progress has been made in every branch of animal physiology and these are steadily finding application in feeding practice: farmers now talk knowledgeably about balanced rations, vitamins, antibiotics, and other things unknown to an earlier generation. Some diseases—e.g. mastitis, milk fever, and others—still cause serious losses. But there have been many triumphs: bovine tuberculosis, helminths in sheep, and various other troubles have been brought under control.

Finally, all branches of agriculture have benefited by the new machines and implements provided by the engineering industry: implements that accomplish their work better, more speedily, and with far less expenditure of labour than the older appliances. They have enabled great areas of land formerly waste to be opened up, and have made possible the production of more valuable crops than those hitherto grown. The cultivation of rice has been mechanized in Malaya, British Guiana, and elsewhere, and Brazil and certain other tropical countries have now begun to manufacture tractors. A Machinery Testing Unit has been set up in East Africa under the direction of the British National Institute of Agricultural Engineering.

Many of the advances described above have been made by men who recorded their results in published papers and who have therefore 'left a name behind them'. But many are the result of a great number of small unrecorded improvements, made by men unremembered and without renown, but whose works have lived on and lightened the labours of countless cultivators. The peasants themselves are beginning to respond and their example more perhaps than any mode of instruction is likely to hasten the general adoption of improved methods.

Will the next twenty-five years see progress in agriculture as great as in the period now ended? It could and should see far greater progress if peace could be assured, and if sufficient numbers of highly qualified persons could be induced to go out to the underdeveloped regions, not as visitors, but as residents to carry out the investigations necessary for the abundant improvements now becoming possible. Such men are scarce, and greatly in demand, they cannot be mass-produced. The old Colonial Agricultural Service attracted them by the breadth of its scope and its freedom from political vagaries: it is not yet clear that the new governments can offer such favourable conditions. It may be that the leadership in agricultural progress in the underdeveloped countries will pass into the hands of the large industrial organizations, some of which are already doing valuable work in many lands. Only the future can show.

TWENTY-FIVE YEARS PROGRESS IN THE THEORY AND PRACTICE OF MOISTURE CONSERVATION[1]

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MOISTURE conservation is one of the major agricultural problems in the prairie area of western Canada, for moisture is the first limiting factor in crop production. The present paper deals with the conservation and use of moisture under the climatic conditions as found in this region.

The prairie areas lie mainly within the Brown and Dark Brown soil zones where the dominant climatic factors are low precipitation, low relative humidity, high evaporation, and high wind mileage. The mean annual precipitation varies from 11·7 to 17 inches depending on location, and the mean annual evaporation from 17 to 30 inches. About one-half of the annual precipitation falls during the growing season of May, June, and July. It is because of this favourable distribution that crop production is possible without the use of irrigation. However, years of low precipitation are of frequent occurrence and it is seldom that there is adequate moisture for maximum crop growth. Very few crops reach maturity without suffering from drought at some stage of growth. Hot dry days with high winds are of frequent occurrence during June and July, causing an excessive loss of moisture and consequent damage to the crop.

The soils of the Brown and Dark Brown zones were formed on glacial drift which varied from a few to several hundred feet in depth. The till was subject to considerable reworking by wind and water after the retreat of the glaciers, resulting in a wide range of textural classes and moisture-storage capacities.

The farmers tend to follow a wheat-fallow or wheat-wheat-fallow rotation, depending on soil-moisture conditions and weed infestation at seeding time. Coarse grains and flax may be substituted for wheat on occasion, though the major portion of the land is seeded to spring wheat.

One of the first recorded references to the use of fallow in western Canada, as a means of conserving moisture for the following crop, was made by Angus McKay, Superintendent of the Experimental Farm at Indian Head, Sask. In his report for the year 1889, he wrote: 'Our seasons point to only one way in which we can in all years hope to reap something. It is quite within the bounds of probability that some other and more successful method may be found, but at present I submit that fallowing the land is the best preparation to ensure a crop.' The more successful method has not been found but the recommendation to fallow the land

[1] Contribution from Division of Field Husbandry, Soils and Agricultural Engineering, Experimental Farms Service, Canada Department of Agriculture.

[2] Retired—formerly Officer-in-Charge.

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has been widely adopted. The importance of weed control during the fallow period was soon recognized and the farmer was often rated according to the weed infestation of his fallowed fields. In an attempt to control weed growth completely the land was often subject to excessive cultivation resulting in a dust mulch. While this was theoretically the ideal condition for prevention of moisture loss by evaporation it was also the ideal condition for erosion. The damage by wind and water erosion was frequently more severe because of excessive cultivation during the fallow year.

Projects dealing with moisture conservation and its use by crops in the prairie area were started by Barnes [1] in 1922 at the Experimental Farm, Swift Current, Sask. He grew crops in watertight tanks, 15 inches in diameter and 5 feet deep, filled with layers of soil as found under natural conditions. The changes in moisture content due to precipitation, crop growth, or cultural operation were determined by periodic weighing of the tanks. This work emphasized the importance of stored moisture, for it was found that crops on land which had been fallowed obtained approximately one-half of the water used from the reserve stored in the soil at seeding time. The lower production on land which had been in crop the previous season was due mainly to less stored moisture, rather than a deficient supply of plant nutrients. The crops grown in tanks tended to produce higher yields and showed a more efficient use of moisture than field crops on similar soils, but there was a close relationship between crop response to moisture supply under the two systems. Soil tanks offer some distinct advantages for studying soil-moisture problems and are used at present by the Soil Research Laboratory.

Definite changes have taken place in the cultural operations as practised by the farmer during the past 25 years. These have been caused by the shift to mechanization, the development of new implements, and new theories in regard to cultural practices. Whereas the bare fallow, deep cultivation, and the use of the binder were the general practice, there has been a shift to surface, or shallow cultivation, with blade- or disk-type implements and the combine harvester which leaves all crop residue on the surface. Coupled with the major problem of moisture conservation, which is almost synonymous with weed control, is the need for the maintenance of a stubble mulch to give a surface condition resistant to erosion by wind. Considerable progress has been made in attaining these objectives.

Part of the programme of the Soil Research Laboratory, which was established in 1936, has been directed toward ascertaining the principles that govern the movement of moisture in unsaturated soils and the use of moisture by crops. Considerable data and information pertaining to these problems have been derived from laboratory, tank, and field projects.

Conservation under Field Conditions

An extensive programme of field sampling for the determination of moisture conservation and its subsequent use by the crop has been carried out for approximately 20 years. Definite locations were established

in fields representing a wide range of soil textures, and samples were collected to a depth of 4 feet at periodic intervals for moisture determination. The bulk density, field capacity, and wilting point were determined for each sampling depth at each site. By the use of suitable factors the moisture content was readily converted into inches of available water. The terms moisture, or stored moisture, as used in this presentation refer in all cases to water available for plant use.

Soil-moisture conservation starts at harvest time, for in most years the crop has used all of the available moisture to the depth of root penetration by the time it is mature. The roots of the cereals penetrate to a depth of 4 feet under favourable moisture conditions and it is in this reservoir of dry soil that moisture for the next crop is stored.

Data [2] representing over 50 station-years showed a mean conservation of 2·2 inches or 34 per cent. of the precipitation from harvest until 1 May. The percentage conservation from autumn precipitation was high, because the soil was in a receptive condition, loss by evaporation was low, and weed growth at a minimum.

The standing stubble is very effective in holding snow on the field during the first overwinter period. The rate of thaw in the spring may have more influence on the moisture conserved than the actual amount of snow trapped, for a rapid thaw while the land is still frozen may result in a high loss by runoff. Neither early autumn cultivation for weed control, listing, or deep cultivation has shown any appreciable, or consistent, increase in the amount of moisture conserved.

During the May to October period, the time when the fallow was cultivated for weed control, only 1 inch or 13 per cent. of the precipitation was conserved. The low percentage conservation was due to weed growth and a high loss by evaporation. The major part of the rain during this period is in the form of showers of one-quarter inch or less which may be lost by evaporation within a day or two. Only that moisture which penetrates 4 inches or more into the soil is relatively safe from loss by evaporation. As the surface soil tends to dry out to the depth of cultivation between heavy rains, deep tillage may contribute to the loss.

During the second winter of the fallow period an additional 0·7 inch of moisture or 17 per cent. of the precipitation was added to the reserve. This was less than during the first winter for the soil was in a less receptive condition, less snow was trapped by the trash cover than by the original standing stubble and the soil was generally frozen to a greater depth. The total mean conservation of moisture in the upper 4 feet of well-fallowed land was 4 inches or 21 per cent. of the total precipitation during the 21-month fallow period.

This mean conservation of 4 inches of moisture represents only part of the total storage capacity, for under prevailing climatic conditions there is seldom sufficient precipitation to wet the upper 4 feet of soil to field capacity. Systematic sampling of fallowed fields at seeding time has shown that the moist layer of soil, which seldom extends to a depth of 4 feet, has a moisture content approximately 80 per cent. of field capacity. Moisture movement by capillarity practically ceases when the moisture content is reduced to the field capacity but there is a continued

slow movement downward owing to the stress of the drier layers at the lower depths. In years of exceptionally high seasonal precipitation there may be some loss by percolation beyond the 4-foot zone, this being more frequent in the coarse-textured soils which have a lower storage capacity.

An increase in percentage conservation of the limited precipitation would be of distinct advantage in crop production. It is thought that the farmers could, by careful timing of cultural operations, add 1 inch or more to the amount of moisture conserved by fallowing. This could mean an increase in yield of 4 to 6 bushels per acre.

Use of Moisture by Crop

The use of tank and field experiments has given a very clear picture of the rate and amount of moisture used by crops. No attempt has been made to differentiate between the water transpired by the plant and that lost from the soil by evaporation, the total being referred to as the water used, or evapotranspiration. Very little moisture is lost by percolation beyond the root zone of a growing crop.

Data collected from a large number of fields [3] representing various soil types and moisture contents have shown a mean requirement of 10·5 inches of water for a 14-bushel crop of wheat. Each additional inch of available moisture (stored moisture and seasonal precipitation) over 10·5 gave an increase of 4 to 6 bushels per acre. When the total moisture used was less than 10·5 inches the yield dropped very markedly, with a crop failure when the total was only 5 or 6 inches. As the amount of available moisture increased, its efficiency increased also, so that less water was required per bushel of grain. With a mean conservation of 4 inches of moisture in fallowed fields and an average seasonal precipitation of 7 inches, the chances of obtaining 14 bushels or more per acre are quite good. The long-term average yield of wheat for the district under consideration is close to 14 bushels.

In years of high over-winter precipitation and high moisture conservation it may be more advantageous to seed stubble land than to fallow it. By determining the depth of moist soil at seeding time the farmer can make a fair estimate of the prospects of producing an average crop on land that was cropped the previous year. In medium-textured soils a depth of 20 inches of moist soil would approximate to a reserve of 3 inches of moisture. If there were less than 3 inches of reserve moisture, the crop prospects would be poor, for in only 2 out of 5 years is the seasonal precipitation equal to or above the mean of 7 inches.

The clay and clay loams are often referred to as good dry-weather soils, for crops on such soils do not suffer as quickly from drought as those on the coarser-textured soils. This has been attributed to the greater water-holding capacity of the fine-textured soils, but actual measurements have shown very little difference in the amount of available moisture in the upper 4 feet of loam and clay soils at seeding time. It is only in the occasional year of above-normal precipitation that the maximum storage capacity of even the average loam soil is fully utilized. It is suggested that the increased production on the finer-textured soils, when the seasonal precipitation is average, or below, is due to the higher

tension by which moisture is held in these soils rather than to greater initial storage.

A comparison of soils ranging in texture from coarse to very fine [3, 4] showed a wide range in the tension with which the available moisture was held. Approximately 90 per cent. of the available moisture in the coarse-textured soils was held with a tension of less than 2 atmospheres while in the fine-textured soils over 50 per cent. was held at a tension of 8 atmospheres or more. A plant must exert a greater force to obtain the required moisture at the higher tensions; thus early growth and moisture use are less rapid, and a small reserve is left for use later at a more critical period.

Field measurements have shown a more rapid use of water during the early stages of growth by crops on the coarser-textured soils. Such crops frequently suffer from drought at a later date. The most critical stage is during the shotblade and heading period when the use of water is most rapid. A crop with a well-developed root system may use one-quarter inch or more of moisture per day, if available, during this period. This rate is comparable to the evaporation from a free-water surface.

Data on moisture use and crop yield [4] show that the yield on the coarser-textured soils was influenced more by seasonal precipitation than by stored moisture, while on the finer-textured soils, stored moisture had the greater influence. The relationship between crop yield, stored moisture, and seasonal precipitations, as influenced by soil texture, was summarized in the following regression equations where Y represents yield in bushels per acre, R stored moisture, and S seasonal precipitation.

$$\text{Loams (131 stations-years)}\quad Y = 3{\cdot}4R + 2{\cdot}8S - 15;$$

$$\text{Clays (30 station-years)}\quad Y = 2{\cdot}5R + 4{\cdot}3S - 11.$$

When the seasonal precipitation was near normal the clay soils tended to outyield the loams, but when the seasonal precipitation was much above normal, higher yields were obtained on the loam soils. Under the latter condition water had ceased to be the limiting factor and such things as aeration, soil temperature, and plant nutrients were of more importance. Moisture distribution within the profile, root penetration, and humidity also have an influence on transpiration and crop growth.

Factors influencing Conservation

Laboratory experiments have shown that bulk density and particle size have a definite influence on the rate of moisture movement in unsaturated soils, the movement being retarded in a loose or layered soil. Capillary conductivity has an important bearing on moisture conservation for it controls infiltration and distribution of water within the soil profile.

Much of the rain falling on a dry, bare surface may be lost by evaporation within a few days. Long-term records show that 44 per cent. of the precipitation from April to October comes in the form of showers of one-quarter inch or less. Such showers have little effect on the reserve soil moisture unless falling when the surface soil is still wet from a

previous rain. The distribution of the precipitation may have more influence than the amount on percentage conservation or crop growth.

The recommended farm practice is to cultivate only for weed control during the fallow period, using the surface-tillage implement that will give the best weed kill. This will depend on the soil type and moisture condition. Pulverization of the soil and burial of crop residue must be kept at a minimum to give the maximum protection from wind erosion. It is important that cultivation of weedy fields be started early to prevent loss of moisture stored during the previous winter. Even very small weeds will rapidly reduce the moisture content of the soil to a depth of 2 or 3 inches. Only rains of amount sufficient to wet the surface soil to field capacity and make contact with the moist soil at the lower depths will add to the reserve moisture. As such rains are more likely to occur during late May and June, it is important that weed growth be controlled prior to this period.

The use of herbicides for weed control on fallowed land may be effective in reducing moisture loss when applied for emergence control or on young plants. Owing to the selective nature of most herbicides complete control of plant growth, whether so-called weed or volunteer grain, is not obtained. Any plant growth during the fallow period uses moisture that might have been conserved for the future crops. Herbicides may be used effectively in conjunction with, but not in place of, cultural operations during the fallow period.

Field shelter-belts were initially recommended as a means of reducing wind erosion and were planted with this in mind. It was often noticed that crop growth was stimulated near the belt where snow had accumulated during the preceding winter. Measurements of soil moisture at seeding time and harvest showed that the increased crop growth near the belt was closely related to the increased soil moisture due to snow accumulation [5]. The effect was more pronounced in the years when large snow drifts were formed followed by low seasonal precipitation. When soil moisture from snow accumulation was negligible, or when the seasonal precipitation was above normal, little or no increase in crop growth was observed near the belt.

Although shelter belts cause a significant reduction in wind speed and evaporation for a distance to leeward equal to twenty times their height, no appreciable increase in wheat yield is attributed to reduction in transpiration near the trees. The reduction in wind speed near the belt would cause a reduction in transpiration if the crop had access to an ample supply of stored moisture but the effect is limited where crops are grown under soil moisture stress.

Work recently initiated is directed toward ascertaining the effect of wind mileage on evaporation and crop yield, using a lath shelter set up on an area with a uniform soil moisture content at the time of seeding.

The present discussion has been limited to the work of the Soil Research Laboratory in southern Saskatchewan where successful crop production depends on making the most efficient use of the limited moisture supply. However, in planning and carrying out the Laboratory programme, careful consideration was given to the theories advanced

and data published by numerous officers engaged in similar work in other parts of the Commonwealth and the United States. There has been close agreement with the explanations offered and recommendations made by the various authors and acknowledgement is made for the information obtained from these sources.

The next twenty-five years will see the continued advance in the solving of the problems concerned in moisture conservation and the development of new concepts which will aid materially in the more efficient conservation and use of our limited moisture supply.

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SOME ADVANCES IN RESEARCH ON PROBLEMS OF THE ANIMAL INDUSTRY IN AUSTRALIA DURING THE LAST TWENTY-FIVE YEARS

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WITHIN the first 25 years of this century Australia built up a reasonably good organization for the study of disease in domestic animals. The University of Melbourne established a Veterinary Research Institute and teaching Faculty in 1909, and the University of Sydney quickly followed suit. The Departments of Agriculture in the several states appointed veterinary pathologists and established research institutes, mainly between 1923 and 1928. The Commonwealth Government established the Council for Scientific and Industrial Research in 1926, and within this organization Divisions of Animal Nutrition and of Animal Health were soon formed. Since then, scientific research on problems of animal health and of animal production has developed steadily. During the last 25 years it has made steady progress in the development on the sound foundation laid earlier.

The first animal problems to be faced in this young country were those associated with the control or prevention of infectious diseases. The etiology of some of these diseases, especially those of sheep, was unknown. We have been protected from the introduction of most of the serious contagious diseases of other livestock countries by the wide oceans and by a very efficient quarantine service. With advances in knowledge, control of infectious diseases became better. Then stock-owners became increasingly more interested in the application of newer methods for the improvement of the quality of their livestock and for improved animal production.

Some of the advances in knowledge that have been made through experimental investigation during the last 25 years are briefly mentioned below.

Contagious and Parasitic Diseases

Tuberculosis in livestock has been brought under better control mainly by a wider use of diagnostic methods and the slaughter of affected animals. In attempted eradication of the disease from dairy herds the occasional failure of chronically affected animals to react to the intradermal tuberculin test has presented a serious problem in most countries. Gregory [1] contributed to a solution of this problem by evolving the short thermal tuberculin test. This is used as a supplementary test and as a check test in problem herds. It has given very satisfactory results.

Contagious abortion (brucellosis) has been the most widespread disease of dairy cattle in Australia. It caused serious wastage, especially at the first pregnancy when the incidence of abortion was commonly 30 per

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cent. or more. An attempt was made to prevent this wastage by the use of a live vaccine made from culture of *Brucella abortus* strain 19, evolved in U.S.A. The use of an accurate dose of living bacteria under field conditions in a widespread continent created problems which had to be solved. Methods to increase longevity and antigenicity of the vaccine and to improve the serological and immune response in inoculated cattle were investigated. Rodwell [2] found methods to improve the longevity of the vaccine. Campbell and Rodwell [3] found that antigenicity is a function of size of dose at any site of injection, and that response is greater after intracutaneous or intracaudal than after subcutaneous inoculation. They [4] also found the incidence of infection in vaccinated calves was about 3 per cent. as against 62 per cent. in controls. This was confirmed by Gregory [5, 6, 7] with larger groups exposed to natural infection during the first and second pregnancies. Compared with control unvaccinated cattle, a reduction of 71 to 87 per cent. in the expected abortion rate was effected by calfhood vaccination. A field investigation was started in Victoria in September 1943. Over a period of 30 months, 30,000 head of dairy cattle were vaccinated. The results proved very favourable; the abortion rate in the vaccinated animals was reduced to 1·09 per cent. in 1946. The method was extended to the other states. By the end of June 1952 approximately one million cattle had been vaccinated. Vaccination with strain 19 has become established practice.

Little or no original work has been done on *vibriosis* and *trichomoniasis* of cattle but they have been recognized as making some contribution to the general problem of infertility of dairy cattle which is under investigation.

Contagious bovine pleuropneumonia was introduced into Australia as long ago as 1858. It spread to all parts of the Commonwealth except to the island state of Tasmania. Epizootics of the disease have caused serious losses in the past. Although some measure of control was obtained, it was not until the work of Turner and Campbell resulted in a reliable diagnostic complement-fixation test [8, 9, 10] that eradication of the disease from definite areas became possible, especially from the states of Victoria and New South Wales. Reintroduction has occurred in these areas from time to time. The evolution of a living-culture vaccine [11] gave a valuable prophylactic measure which was adapted for the protection of in-contact cattle and for cattle being droved on the long stock routes. Experimental studies, including the measurement of the protective value of vaccination, were made possible by the discovery of a reliable means of experimental reproduction of the disease with nebulized artificial cultures of the causal micro-organism [12].

Bacterial mastitis has been one of the most troublesome diseases of dairy cattle in most countries. Advances in bacteriology, especially in the identification and classification of streptococci, by workers in Great Britain and elsewhere made it possible for an experimental epidemiological study of the disease to be undertaken in Australia. The investigation was started in 1935 when an experimental herd was established by selecting non-pregnant heifers. As each animal came into production,

systematic bacteriological examinations were started on the individual quarters of the udder, thus giving a detailed bacteriological and clinical history of each quarter. A great deal of valuable information was obtained. The data covering the first two lactation periods were published [13] in 1940. Further, the occurrence of the disease in commercial herds was studied, as well as methods of treatment and control by udder infusion with sulphanilamide or with dilute solutions of acriflavine. These control methods did not give entirely satisfactory results. It was postulated that good milking-shed hygiene and gentle methods of milking, along with the introduction of none but uninfected cows into the herds, were fundamental to control. Udder infusion with bactericidal substances was judged to be usually too irritant. The ideal substance for udder infusion in streptococcal mastitis eventuated when penicillin became available [14]. Thorough investigation of penicillin for the elimination of streptococci from the udder [15, 16, 17] proved its great value in treatment and as an adjunct to the control of streptococcal mastitis, but it failed against staphylococcal infections. However, actual control of mastitis depends mainly in efficient milking-shed hygiene including the use of adequate disinfection of milking-machine teat cups [18].

'*Redwater*' of calves, an acute febrile disease, had been known for many years to cause serious losses of stock in most states of the Commonwealth. In 1949 it was discovered in Queensland to be due to infection by Leptospira [19]. In Western Australia [20] and in Victoria [21] these findings were confirmed. The commonest infection was by *L. pomona*, but *L. mitis* also occurred. Overt clinical manifestation was found mainly in calves, but sometimes in adult cattle; horses, cattle, and swine were commonly carriers of the infection, which from time to time became manifest in dogs and man. With advance in knowledge, preventive methods became possible.

Australia is relatively free from pathogenic protozoan parasites. *Babesiosis* of cattle has, however, created a problem of great magnitude in the higher rainfall tropical and subtropical regions. *Babesia bigemina* and *B. argentina* are now known to be the causal parasites. *Anaplasma marginale* is usually associated with these parasites, but is of low pathogenicity. Prior to 1932 it was believed that only *B. bigemina* was present in tick-fever of cattle, but more recently *B. argentina* has been found in Queensland to be present, often in a pure state, in natural outbreaks of the disease. Cattle born in the tick-infested areas acquire a natural infection which protects them from disease manifestation. Store cattle and stud stock moved into these areas from tick-free areas have to be protected from the disease by artificial immunization, sometimes known as premunization. Much experimental work has been carried out by Legg in the determination of the identity of the parasites and of the constitution of the protective inoculation [22].

The *cattle tick*, as well as being a vector of the blood parasites, causes a great deal of worry to the animal and damage to the hide. For many years the tick was kept under control by the use of arsenical dips. Studies on the non-parasitic stages of the cattle tick have yielded informa-

tion of value in the development of control methods [23]. Ticks resistant to arsenic were found in certain areas of Queensland. To meet this threat, DDT was tried. It was found [24, 25] that it gave a good kill of the ticks and protected animals for several days against reinfestation. The problem was to devise methods by which the dip preparation would remain active over long periods in vats increasingly fouled by organic matter. This problem has been largely overcome. No DDT-resistant strain has yet been found that cannot be controlled by dipping at more frequent intervals in higher concentrations of the toxicant. Other acaricidal substances have been investigated, but highly resistant strains have been found to develop readily.

There are several contagious diseases of sheep which have proved troublesome. Of these, *contagious footrot* is the most serious, especially in higher-rainfall areas; it is absent in the semi-arid pastoral areas. The etiology and the contagious nature of the disease were discovered by Beveridge [26]. Methods for its eradiction from individual properties were devised. They proved successful, but the task was difficult, especially when rainfall was above average. Copper sulphate and formalin solutions were used for curative and prophylactic treatment of the feet of sheep. More recently [27], chloromycetin has been used for curative treatment with success.

An unexpected addition to the list of infectious diseases of sheep was made in 1949 when it was found on a property in Queensland that an outbreak of pyaemia was in fact an outbreak of *melioidosis* [28, 29]. Other minor occurrences have been recorded in Queensland, but fortunately the disease is restricted, and dies out readily when standard hygienic precautions are taken.

An *infection of the epididymis* of rams has been known for some years to cause minor trouble. It was found to be due to a micro-organism possibly belonging to the genus Brucella [30]. The incidence of the disease has remained stationary in merino rams for many years, but a more serious outbreak with a high incidence occurred in rams of British breeds in South Australia [31]. Culling of affected animals and isolation of young rams has brought the disease under control.

Infections of sheep by strains of *Salmonella* have in recent years been found to be relatively common. Outbreaks of disease with severe mortalities have usually been associated with lowered nutrition or with nutritional stress when sheep are transported over long distances [32]. These losses have been brought under control by better attention to good roughage content of the diet before transport, to education in hand feeding, and to better provision of food for the animals during transport [33].

Viruses do not cause many serious disease problems of livestock in Australia. The poultry and pig industries are those branches mainly affected. *Contagious ecthyma* of sheep is widespread but rarely causes serious outbreaks. A live vaccine is being used commonly to initiate resistance in the lambs each year. *Ephemeral, or three-day, fever* of cattle became manifest in northern Australia [43] in 1936. It spread rapidly in the susceptible population and caused loss of production in dairy

herds. It is now enzootic and causes little trouble. *Swine fever* and *Newcastle disease* of poultry have been introduced on more than one occasion but have been eradicated after praiseworthy work on the identification of the viruses and in the study of the epidemiology. *Fowl pox* has been present for many years. Prophylactic vaccination is widely used as a control measure. *Infectious laryngotracheitis* was first recognized in Australia in 1935. Prophylactic vaccination is widely used. *Avian encephalomyelitis* was first recognized in 1939 in New South Wales but is absent elsewhere. *Avian leucoses* are widespread, but knowledge has not advanced far enough to enable reliable control methods to be evolved.

A very large amount of work has been carried out on verminous infestations of livestock during the last 25 years. Possibly the most important part of this work has been the study of the epizootiology and parasitic life-cycles of *gastro-intestinal infestations* of sheep and cattle by long-range experimental methods. A great deal of basic knowledge has been obtained. Much of this, including that bearing on climatology, has proved of practical value in the development of control methods. The basis of these methods is the attack on the contamination phase of the life-cycle of the parasite, and the strategic and tactical use of anthelmintics. The seasonal pattern has formed the basis of strategic anthelmintic administration, whereas variable weather conditions, nutrition of the animal, and the bionomics of the free-living stages of the parasites have formed the basis of the tactical attack. The whole subject of helminthic diseases of livestock is reviewed by Gordon [34].

Work has also proceeded in the control of *lice and keds* of sheep, but this calls for no special mention as it follows very closely that carried out in other countries. The evolution of the newer insecticides has created new problems, one of which is the increase in the incidence of the *itch-mite*, which was discovered [35] in 1941. It seems that the use of the older arsenic-sulphur powder dips kept the itch-mite under control so well that its presence was not suspected. The newer insecticides fail to control it, and thus a troublesome problem is created, although it is known that polysulphide preparations are effective [36].

Cutaneous myiasis, or blowfly strike, of sheep created one of the most serious problems of the sheep and wool industry of Australia. For many years it was studied as an entomological problem. Useful information was obtained. It became apparent that the cause of primary flystrike was *Lucilia cuprina* which was responsible for most of the trouble. The most widespread form of the disease was breech or crutch strike of ewes although body strike was troublesome in the summer-rainfall regions. The common control methods included the shearing of wool from around the breech and tail, and the use of arsenical solutions or suspensions applied as a jet to the breech. The results of the earlier investigations were summarized in the first report of the Joint Blowfly Committee [37]. A little later it was recognized more clearly as an animal-health problem. Systematic observations showed that some types of sheep were highly susceptible to crutch strike and were frequently reinfested, whereas others were relatively resistant. Susceptibility or predisposition

was correlated with conformation of the breech [38]. This was a great step forwards. Prevention was then attempted from two angles, one by selective breeding against wrinkly and excessive skin of the breech, the other by the surgical removal of excessive skin, first suggested by J. H. W. Mules. Both methods have been used, usually conjointly, with great success. The development of this second phase in the attack on the problem has been summarized by the Joint Blowfly Committee [39, 40]. The surgical treatment of the breech has been made more radical and the optimal tail length has been determined, although later surgical adjustment of skin folds about the tail may be necessary in some types of sheep. More recently, experimental methods have shown that some of the newer insecticides are valuable in the prevention of head strike in rams, of body strike generally, and of breech strike [41, 42].

Diseases due to Commensal or Semicommensal Micro-organisms

Infectious diseases under this category are rarely if ever contagious. They are frequently localized in enzootic areas because of soil, climatic, or biological factors. Soils of particular character form the natural habitat for some bacteria capable of harming animals, for example *Clostridium tetani*, *Cl. botulinum*, and *Cl. oedematiens*. Black disease, *infectious necrotic hepatitis*, of sheep has been known in Australia for many years. As a result of scientific investigations by Dodd, by Albiston, and finally by Turner [44], it was found to be due to spores of *Cl. oedematiens* lodging in the liver where they remained dormant unless stimulated into growth by the effects of liver damage from wandering larval liver flukes. The disease, which was devastating in certain defined but large areas, was brought under control mainly by the use of a prophylactic vaccine. However, fluke eradication was capable of producing control of the disease. These results were obtained just over 25 years ago but are mentioned here because of their great importance and because they serve to illustrate an enzootic non-contagious type of infectious disease first identified in Australia.

Infectious entero-toxaemia of sheep has some features in common with black-disease, since it produces rapid death and is due to an anaerobe, *Cl. welchii* Type D, with a soil habitat. The etiology of the disease, which is probably not always enzootic strictly, was described by Bennetts [45] in 1932. Death is due to the absorption of the specific bacterial toxin from the gut. Prophylactic vaccination has given a good measure of control, but some limitation of food intake, especially in the adult, is of preventive value.

Botulism is another disease which comes under this category, since it is due to ingestion by animals of preformed toxin of a soil Clostridium either in carrion or in damaged vegetable matter. Earlier it had been determined that cattle under nutritional stress may eat affected carrion, or horses may eat damaged hay or grain, in which the toxin of *Cl. botulinum*, usually Type C in Australia, was present. Later, sheep under nutritional stress in Western Australia [46] were affected by the disease after consumption of carrion resulting from systematic poisoning of rabbits. The disease was brought under control by the use of a prophy-

lactic vaccine, but improvement of husbandry was also effective. The vaccine is also successful in preventing botulism in horses and cattle.

Caseous lymphadenitis of sheep came under investigation because the presence of lesions led to the condemnation of carcasses. It was found that lesions in the lymph glands resulted from infection of skin wounds most commonly produced during shearing operations. The wounds were not uncommonly infected by the causal micro-organism, *Corynebacterium ovis*, to be found in the soil of the camping grounds of sheep [47] when moisture and temperature were favourable. The disease is not directly conveyed from sheep to sheep. Hygienic and husbandry precautions have reduced the incidence of the disease.

Erysipelothricosis is another disease in this category. The micro-organism is ubiquitous in soil It infects the umbilicus of newborn lambs and thus leads to an infectious arthritis. It contaminates dipping vats containing no bacteriostatic substance, and thus produces infection of wounds of sheep if they are dipped immediately after they are shorn. It produces a more serious infectious disease in swine if they have access to soil constantly contaminated over long periods by faeces and urine. Under these conditions the virulence of the micro-organism is built up. The application of knowledge on the epidemiology of these diseases enables their being brought under control.

Mycotic dermatitis of sheep, and occasionally of horses and cattle, has become more troublesome in Australia in recent years. It is believed by the present writer to be due to a soil actinomyces which commonly contaminates the fleece and skin of sheep, but invades the skin, usually in circumscribed areas, when free moisture is present for some days. The use of the newer insecticides, for the control of ectoparasites, in the absence of bacteriostatic or fungistatic substances, has appreciably increased the incidence of the disease in some regions. Control methods are obvious. Some evidence has been produced to suggest that under some climatic conditions ewes with lesions about the face may infect lambs.

Non-infectious and Environmental Diseases

Early attention was given to the identification of plants injurious to stock. Possibly plants producing *prussic acid poisoning* have been the most troublesome. Most of these are well known now, and successful steps can be taken to prevent animals from having access to them. *Nitrite poisoning*, from the consumption of specific plants and from grazing sheep on young oat crops on some soils of high nitrogen content, has become well known and can be avoided. Much systematic and experimental work on plants poisonous to stock has been carried out during the last 25 years. Most of this information has been collated [48, 49], and the results of investigation made freely available.

The *hepatotoxic action* of *Heliotropium europaeum*, a summer-growing annual, remained unsuspected for many years, mainly because sheep can, as a first experience of it, graze the plant in a pure stand for the whole of the growing period without untoward results. If they graze the plant again in the following year, chronic liver damage may cause the death of

50 to 70 per cent., or more, of the flock. Field and experimental investigations [58] have elucidated the problem, which had reached heavy proportions, and precautions against the grazing of the plant have brought the disease under control.

Kimberley (*'walkabout'*) *horse disease* in northern Australia has been a problem of great economic significance to cattle-station management for many years. Field and experimental investigations [59] have recently proved it to be caused by the consumption of *Crotalaria retusa*, which has a hepatotoxic action similar to that of *H. europaeum* and *Senecio* spp. Since the plant grows abundantly only in the areas of the river courses subject to flooding, the disease has been brought under control by the exclusion of horses from these areas, by the erection of fences or by other means, during the wet season of the year.

Birdsville disease has also caused very heavy losses of horses, mainly in central Australia and Queensland. Field and experimental investigations [60, 61] have proved it to be due to the consumption of *Indigofera enneaphylla*. The disease can be prevented if horses are kept from grazing the plant, but this is sometimes very difficult. This plant has no definite hepatotoxic action. The toxic principle has not yet been identified.

In addition, some pasture plants of great economic importance have proved very harmful to grazing stock under certain conditions. An outstanding example of this is the occurrence, during the period 1940–50, of breeding troubles in merino ewes grazing on pastures in Western Australia in which the annual subterranean clover, *Trifolium subterraneum*, had become dominant. The early Dwalganup strain was mainly incriminated. Under war-time conditions with restrictions on the availability of superphosphate, but with climatic conditions favouring early germination and luxuriant growth of the clover, the troubles reached an alarming peak [50] in 1943. The clinical and pathological disturbances suggested an oestrogenic action [51, 52] which was later demonstrated [53] with extracts of the plant. The oestrogenic substance was identified as genistein [54]. With the normal use of superphosphate, and pasture management, including the use of temporary leys, to prevent clover dominance, the disease was brought under control.

Another valuable pasture plant, *Phalaris tuberosa*, was known for some years to be associated with the development of *staggers* in sheep, due to myelin degeneration in the central nervous system [55]. It occurred only in some regions, and usually followed the early autumn rains. It was associated with a low intake of cobalt by the animal, and was prevented when the intake was raised [56, 57]. It is believed that the cobalt enables bacterial action in the rumen to destroy the toxic substance, which so far has not been isolated and identified.

Subterranean clover has also been found to give rise to phytogenous chronic *copper poisoning* in sheep in certain areas under particular climatic conditions [62]. The clover grows very luxuriantly, is dominant in the pasture, has a high-normal copper content, but a very low molybdenum and inorganic sulphate content. Prevention of the disease is based primarily on the control of clover dominance.

Consumption of hepatotoxic pyrrolizidine alkaloids in *H. europaeum* and other plants leads to the development of a hepatogenous chronic copper poisoning which is favoured if the sheep are grazed during the winter and spring months on subterranean clover pastures. The primary control is the prevention of consumption of the hepatotoxic plants.

The occurrence of chronic copper poisoning in sheep has led workers to study copper metabolism and the factors controlling the uptake and storage of copper by the animal. The low intake of molybdenum and inorganic sulphate favours a high uptake and storage of copper in the liver of sheep. The results of the experimental work have been reviewed [63]. The new knowledge has practical value in the control of chronic copper poisoning.

Earlier experimental work revealed the importance of a deficient intake of copper, and the nature of the disease processes in the sheep. *Ataxia* in the lamb was discovered [64] to be due to a copper deficiency in the ewe and lamb. Further work has shown that a deficiency of copper in soil and pasture is widespread in Australia, and is accompanied by copper deficiency in sheep and cattle. Horses are unaffected. Experiments showed that an *enzootic marasmus* in cattle and sheep in Western Australia was prevented by the administration of limonite [65]. The curative substance was present in the iron-free fraction and was found to be cobalt [66]. '*Coast disease*' of sheep in South Australia was shown to be due to a deficiency of both cobalt and copper [67]. The discoveries have been of great value in the evolution of disease-preventive methods and in the improvement of animal production.

Applied Physiology—Animal Production

Much experimental work has been carried out in recent years in the field of applied general and special physiology, with a view to the improvement of methods of animal husbandry and of animal production.

Probably the problem with the most serious consequences to the animal industry is that of recurrent droughts. The improvement of water conservation and the tapping of the artesian basin have extended the areas available for grazing, and have made possible an increase in livestock population. Thus, water for stock is less of a limiting factor in periods of drought than it used to be. Improvement of pastures in the better-rainfall areas has also permitted more stock to be carried. Conservation as hay or grain of cereal crops, of pasture, and of lucerne has made more food available for stock during the regular seasonal periods of latent plant growth. Although advances have been made in pasture and in crop production, as well as in methods of conservation, fodder conservation is still totally inadequate to meet the requirements for any serious drought period. Costs of labour and material limit the extent to which conserved food can be used for drought feeding over long periods of months. Methods of making supplementary feed available, or of maintaining sheep wholly on conserved fodder, have varied. Pastoralists frequently used common salt, or some other substance, as a repellant in the feed to limit the amount consumed per day by sheep, but without great success. The method, although commonly used, was not based on

physiological principles. Is it necessary for a sheep at low maintenance level, with a rumen something like a small storehouse, to eat a nicely calculated amount of food per day? To answer the question, a maintenance diet containing good roughage was given to one group daily, and to another group seven times the amount was given once a week; it was consumed over a period of about three days. The weekly-fed sheep were equally well maintained as the daily-fed sheep [68]. The method was more extensively studied under experimental conditions [69], when it was found that weekly-fed sheep were at an advantage. The labour costs were greatly reduced.

A successful attempt was made to conserve pastures by the destruction of the wild-rabbit population through the agency of a virus disease, *myxomatosis*. The disease spread widely and rapidly, and produced a death rate of over 90 per cent. in the epizootic areas. The improvement in the pastures and in animal production was very spectacular. The disease has decreased in killing power and there is evidence of development of some resistance of the residual rabbit population. Other methods of destruction are being used with success to supplement the ravages of the virus disease. Future developments cannot be predicted at this time.

A great deal of experimental work has been carried out on the influence of nutrition, and of other factors, on the growth of the fleece of sheep. The knowledge obtained forms an essential background for experimental studies on wool production and sheep breeding. Also much work has been done on the study of the skin and its accessory organs of the sheep. The knowledge obtained provides essential yardsticks for measuring results of physiological, breeding, and genetic studies. The results have not yet reached a stage at which they can be widely applied. They will be used to raise production, for the average fleece weight of merino sheep has been approximately static for the last twenty years. Early results from the genetic studies show that mass selection on measured phenotype is capable of producing appreciable improvement, and has a wide general application.

Cattle-breeding and genetic experiments are in progress. These are long-range, and are designed especially to examine problems of adaptation of cattle to hot environments. It will be some years before results of practical application can be obtained.

Long-range poultry-breeding and genetic studies have also been actively pursued. It has been found that family selection is not superior to mass selection. Under the impact of continuous inbreeding, hatchability was reduced, chick mortality increased, and egg production only slightly increased.

Attention has been given to reproductive physiology, especially in sheep. Results have been applied to breeding practices with advantage.

In general, during the last 25 years animal husbandry has improved greatly as a result of the application of new knowledge. Wastage has been reduced, and livestock numbers have been increased. If the present scientific research produces the results expected, the future should show an increase in the level of livestock *per capita* production.

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TWENTY-FIVE YEARS' PROGRESS IN BREEDING NEW VARIETIES OF WHEAT FOR CANADA[1]

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In reviewing the wheat-breeding work carried out in Canada during the 25-year period, 1933–57, it is necessary to consider breeding programmes conducted in different wheat-growing regions having different soil and climatic conditions, and therefore requiring different types and varieties of wheat.

The Wheat-growing Regions

The main wheat-producing regions of Canada are indicated in Fig. 1 which shows, by means of dots, the comparative concentration of wheat acreage in different parts of Canada. The main concentration is seen to be in the Prairie Provinces (Manitoba, Saskatchewan, and Alberta), and a secondary concentration is in southern Ontario. Separating these two wheat-growing regions is the Precambrian Shield, a vast region of rocks, lakes, and forests. Other areas in the eastern provinces and in British Columbia produce relatively little wheat.

Average annual acreage and production of wheat in Canada in the 50-year period 1908–57 were as follows: 21,125,000 acres, producing 353,841,000 bushels, or 16·8 bushels per acre. In 1957 when Canada produced 373,508,000 bushels of wheat, the Prairie Provinces produced 94·3 per cent. of this total, while Ontario produced 5·3 per cent.; and the remaining six provinces together produced only 0·4 per cent., which production is, however, of considerable local importance.

The Prairie Provinces

The main wheat-growing regions of the Prairie Provinces have a continental grassland climate with low precipitation, short, warm summers, and long, cold winters. The annual precipitation is about 10 inches in the region of south-eastern Alberta and south-western Saskatchewan, increasing to the northward, westward, and eastward of this region to reach 20 inches or more in the northern fringe of the wheat area, the foothills of the Rocky Mountains, and the Red River Valley of Manitoba. Fortunately, most of the precipitation occurs in the spring and summer months and is available to the growing crop. While the generally low precipitation is responsible for the relatively low yields of wheat in the Prairie Provinces, it is also the main factor responsible for the high protein content and good baking quality of this wheat.

Hard red spring wheat (bread wheat) is the principal type grown in all areas, usually producing more than 300 million bushels per annum.

[1] Contribution No. 224 from the Cereal Crops Division, Experimental Farms Service, Canada Department of Agriculture, Ottawa, Canada.

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Winters are too severe for successful production of the present varieties of winter wheat except in southern Alberta where milder winters permit the growing of hard red winter wheat (some 4,000,000 bushels per year, or about 1 per cent. of Canada's wheat production). In the latter area soft white spring wheats of low protein content are also grown (about 1,000,000 bushels). These soft wheats, used for pastry flour, are produced on irrigated land. Varying amounts of durum wheat have been produced in the southern parts of the Prairie Provinces, with an average

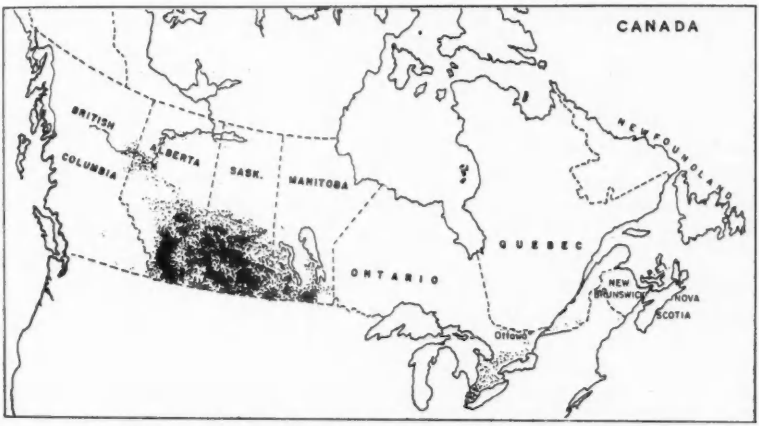

FIG. 1. Concentration of wheat acreage in Canada in 1951.
The density of stippling indicates the relative concentration of wheat acreage.

annual production of about 18 million bushels in the last decade, and a record of 44·4 million bushels in 1957.

In the eastern section of the prairies, including Manitoba and eastern Saskatchewan, stem rust (caused by *Puccinia graminis tritici* Eriks. and Henn.) and leaf rust (caused by *Puccinia triticina* Eriks.) are the chief hazards to wheat production. Wheats for this area must be resistant to stem rust and leaf rust. In the drier areas (south-western and west central Saskatchewan together with southern and central Alberta) attacks of the wheat stem sawfly (*Cephus cinctus* Nort.) and drought are the main hazards. Wheats for this area should have resistance to drought and to wheat-stem sawfly. In southern Alberta winter wheats must be resistant to winter killing, and irrigated spring wheats require resistance to stem rust. In the northern fringe of the wheat region of the Prairie Provinces the growing season is short, necessitating the use of early maturing spring wheats to avoid frost damage.

British Columbia

In spite of the relatively small amount of wheat grown in British Columbia a considerable number of winter-wheat and spring-wheat varieties are used. The most troublesome disease is bunt, or stinking

smut, caused by the fungi *Tilletia foetida* (Wallr.) Liro and *T. caries* (DC.) Tul.

Ontario

The main wheat-growing area of Ontario is in the south where the mild winters permit the growing of soft white and soft red winter wheats of low protein content suitable for the manufacture of biscuit, cake, and pastry flours. In 1957 more than 98 per cent. of Ontario's wheat was winter wheat. Winter wheats for Ontario do not require a high degree of winter hardiness, but should be sufficiently hardy to survive abnormal winters. The diseases, loose smut (caused by *Ustilago tritici* (Pers.) Rostr.) and bunt, are relatively more important than the rusts in this area.

Quebec and Provinces to the East

In these provinces the growing of winter wheat is more hazardous than in southern Ontario, and spring wheats (both red and white) are mainly grown.

Neighbouring Wheat Areas of the U.S.A.

Except for the northern wheat-growing region of the Prairie Provinces all of the main Canadian wheat-producing areas discussed above adjoin similar wheat-producing areas in the United States. Canada and the United States are, therefore, breeding wheats to solve similar problems. As a result many wheats developed in the United States are used in Canada and varieties of Canadian origin are similarly grown in the United States. While this paper is concerned with Canadian wheat breeding, varieties introduced from the United States must be discussed to give a complete account of the changes of varieties to meet production problems.

The Situation at the Beginning of 1933

Organization of Wheat Breeding

At the beginning of 1933 some of the main features of the present organization for wheat breeding in Canada had already been established. Wheat breeders, agronomists, plant pathologists, and cereal chemists were co-operating on a regional basis to develop and test new varieties. The Canada Department of Agriculture and a number of universities were carrying out both breeding work and fundamental investigations, with the latter emphasizing fundamental studies. Associate Committees of the National Research Council of Canada, including in their membership representatives of all institutions and personnel mentioned above were co-ordinating their work on wheat. The system of regional variety tests known as the Co-operative Tests had been instituted. A licensing system under the Canada Seeds Act had been in successful operation since 1923 for the control of wheat varieties. Under this act only seed of licensed varieties could be sold in Canada. A licence was granted to a new variety only upon adequate proof that it was superior

in some way to varieties already established. The milling and baking qualities of new varieties for the Prairie Provinces were being carefully checked by at least two cereal-quality laboratories before a licence was granted.

Investigations and Breeding

At the beginning of 1933 the breeding of early-maturing spring wheats at Ottawa for all of Canada was well advanced. The organization of plant breeders and plant pathologists at Winnipeg working in co-operation with cereal chemists to develop high-quality disease-resistant wheats was well established. Plant pathologists had made annual surveys and identifications of races of stem rust and leaf rust from 1919 onward. They had, for example, identified race 56 of stem rust which later, in 1935, caused enormous damage to the wheat crop. Important fundamental studies had been made in the cytology of species hybrids in the inheritance of stem-rust resistance in wheat. In Canada, as in the United States, plant breeders had developed rust-resistant spring wheats which were then in advanced stages of testing and increase.

The Main Wheat Varieties

In the Prairie Provinces at the beginning of 1933 the main wheat variety was Marquis. The variety Ceres was also grown to a large extent in Manitoba and eastern Saskatchewan. Both Garnet and Reward were grown in the northern fringe of the wheat area because of their early maturity. Marquis, Ceres, and Reward all produced flour of good baking quality but Garnet was deficient in this respect. All four varieties were susceptible to the major diseases, stem rust, leaf rust, bunt, and loose smut except that Marquis was resistant to bunt. No sawfly-resistant wheats were available in Canada.

In eastern Canada the leading winter wheat was Dawson's Golden Chaff, a soft white winter wheat producing good-quality pastry flour. Although a high-yielding, strong-strawed variety, it had insufficient hardiness in abnormal winters, and was susceptible to stem rust, leaf rust, bunt, and loose smut. The main hard red spring wheat, Huron, was also susceptible to these four diseases, and it was deficient in bread-making quality. Marquis, Reward, and Garnet were grown on a limited scale.

The Period of 1933–57

Organization

The organization already referred to was much further developed and extended during the period of 1933–57. The Canada Department of Agriculture further developed its headquarters staff at the Cereal Crops Division, Ottawa, to co-ordinate wheat-breeding work in Canada, to carry out fundamental research, and to breed wheats for eastern Canada. This Department, in co-operation with the universities, also organized a large wheat-breeding project within each of three regions in the Prairie Provinces, namely: the Rust Area (Manitoba and eastern Saskatchewan) with regional headquarters at the Cereal Breeding Laboratory, Winnipeg, Man.; the Drought Area or Prairie Region with

headquarters first at Swift Current, Sask., and later at Lethbridge, Alberta; and the Early Wheat Area or Northern Area with headquarters at the Experimental Farm, Lacombe, Alberta. At each of the three headquarters specialists work as a research team on wheat breeding and related problems, and the cerealists and agronomists at the various experimental farms in the region co-operate in testing material at the various stages of development.

At Winnipeg, for example, the Cereal Breeding Laboratory has a breeder for common wheat and one for durum wheat, a wheat geneticist, a cytologist, and a technician for the development of equipment. Quality prediction work is also being developed. The Plant Pathology Laboratory has pathologists working on stem rust, leaf rust, smuts, root rots, and bacterial and virus diseases of wheat. This Laboratory has also a physiologist studying both the rust and its wheat host, and a rust cytogeneticist. Entomologists have recently joined the group at this location. Tests of new wheat varieties for milling and baking quality are conducted at the Cereal Crops Division, Ottawa, and at the Grain Research Laboratory of the Department of Trade and Commerce at Winnipeg.

The organization of the group at Lethbridge, Alberta, is on the whole quite similar to that at Winnipeg, but with such differences as are called for by different problems. In addition to three wheat breeders there are cytogeneticists, plant pathologists, entomologists, a physiologist, and a chemist. Quality prediction work is being developed.

The more recently organized wheat-breeding project at Lacombe, Alberta, has a smaller organization.

In the work of these groups the project leaders visit the co-operating units during the growing season. Each project group has an annual meeting, usually in the winter, when all data for the past season have been assembled, where results are assessed and general plans for future work are made. Co-ordination of all wheat work in western Canada is achieved through the annual meetings of the Associate Committees on Plant Breeding, Plant Diseases, and Grain Research, organized by the National Research Council of Canada. These committees have members representing all institutions doing research work on wheat in western Canada. They review data on all prospective new wheat varieties to appraise their field performance, disease resistance, and quality.

Varieties Licensed during 1933–57

In the 25-year period of this review thirty-three wheat varieties were licensed in Canada, of which seventeen had been developed in Canada, fifteen in the United States, and one in Sweden. These are listed in Table 1 with data on origin, year of licence, and reaction to the four major wheat diseases. For convenience of discussion the varieties are grouped according to the general type to which they belong and the region of their main use. All of these wheats except the four durum wheats (*Triticum durum* Desf.) are varieties of common wheat (*T. vulgare* (Vill.) Host). More detailed information concerning wheat varieties in Canada may be obtained from various publications [e.g. 1, 2,

3], and the distribution of varieties in the Prairie Provinces has been dealt with by Greaney and Barnes [4]. The story of the breeding of most of these varieties may be followed in four bulletins of the Canada Department of Agriculture [5, 6, 7, 8] and in review articles by Neatby [9], Goulden *et al.* [10], and Goulden [11].

TABLE 1. *Varieties of Wheat Licensed in Canada in the Period 1933 to 1957 inclusive, their Origin and Disease Reactions*

Variety	*Where originated**	*Year of licence*	*Reaction to physiologic races of disease organisms prevalent in 1950–6†*			
			Stem‡ rust	*Leaf‡ rust*	*Bunt*	*Loose smut*
WESTERN CANADA						
Hard red spring wheat for Manitoba and eastern Saskatchewan (rust area)						
Thatcher	U.S.A.	1935	(MS)	S	S	R
Apex	Saskatoon, Sask.	1937	(MS)	S	MR	MR
Renown	Winnipeg, Man.	1937	(MS)	(MS)	R	MR
Regent	,, ,,	1939	(MS)	(MS)	R	MR
Redman	,, ,,	1946	(MS)	(MS)	R	MR
Lee	U.S.A.	1950	(MS)	(MR)	S	MS
Selkirk	Winnipeg, Man.	1953	R	MR	R	R
Hard red spring wheat for the dry areas of Saskatchewan and Alberta (brown and dark brown soil zones)						
Thatcher (see above)						
Canus	Edmonton, Alta.	1935	S	S	R	S
Rescue§	Swift Current, Sask.	1946	(MS)	S	S	MS
Chinook§	Lethbridge, Alta.	1952	(MS)	S	MS	MS
Lake	Scott, Sask.	1954	S	S	R	MS
Hard red spring wheat for the northern crop areas of the Prairie Provinces and the Peace River region of British Columbia						
Thatcher (see above)						
Saunders	Ottawa, Ont.	1947	(MS)	MS	MR	R
Soft white spring wheat for the irrigated areas of southern Alberta						
Lemhi	U.S.A.	1948	S	S	..	..
Lemhi 53	U.S.A.	1956	MR	S	..	..
Hard red winter wheat for southern Alberta						
Yogo	U.S.A.	1948	S	S	R	R
Winter wheat for British Columbia						
Sun	Sweden	1937	S	S	..	..
Ridit	U.S.A.	1938	S	S	MR	..
Wasatch	U.S.A.	1950	..	..	R	..
Durum spring wheat (amber) for the southern parts of the Prairie Provinces						
Carleton	U.S.A.	1944	(S)	R	MS	MS
Stewart	U.S.A.	1946	(S)	R	MS	MS
Nugget	U.S.A.	1952	S	R	MS	MS
Ramsey	U.S.A.	1957	R‖	MR	MS	S

Variety	Where originated*	Year of licence	Reaction to physiologic races of disease organisms prevalent in 1950–6†			
			Stem‡ rust	Leaf‡ rust	Bunt	Loose smut
EASTERN CANADA						
Soft white and soft red winter wheat						
Rideau (white)	Ottawa, Ont.	1941	S	S	S	S
Cornell 595 (white)	U.S.A.	1946	S	S	S	R
Dawbul (white)	Guelph, Ont.	1948	S	S	S	R
Fairfield (red)	U.S.A.	1950	S	S	MS	R
Genesee (white)	U.S.A.	1952	S	S	S	R
Thorne (red)	U.S.A.	1952	S	S	S	R
Richmond (white)	Ottawa, Ont.	1953	S	S	R	S
Kent (red)	Guelph, Ont.	1957	MR	R	MR	R
Spring wheat						
Coronation (red)	Winnipeg, Man.	1937	(MS)	(MS)	S	S
Cascade (white)	Ottawa, Ont.	1947	(MS)	MS	MS	MR
Acadia (red)	Indian Head, Sask.	1951	(MS)	(MS)	R	MR

* The crosses from which the varieties were derived and the institutions where the varieties were developed are given in the section on 'Discussion of Varieties' (p. 111).

† R = resistant; MR = moderately resistant; MS = moderately susceptible; and S = susceptible.

‡ Rust reactions shown in parentheses indicate present reactions of varieties that were, at the time of their release, resistant to prevalent races.

§ Resistant to wheat-stem sawfly.

‖ Ramsey wheat is resistant to widely prevalent races of stem rust including the ordinary 15B race, but is susceptible to the subrace 15B4 (Can.) which has been fairly commonly distributed for several years.

The general appearance of the thirty-three varieties listed in Table 1 may be visualized from the following classification.

Key to Varieties of Wheat Licensed during the Period 1933–57

Varieties of *Triticum vulgare* (Vill.) Host.
- Head beardless (except for short awns at the tip)
  - Chaff white and smooth.
    - Grain red: Apex, Chinook, Fairfield, Redman, Regent, Renown, Rescue, Ridit, Saunders, Selkirk, Sun, Thatcher.
    - Grain white: Cascade, Richmond, Rideau, Lemhi, Lemhi 53.
  - Chaff white and hairy.
    - Grain red: Lake.
  - Chaff red or brown and smooth.
    - Grain red: Kent, Thorne.
    - Grain white: Cornell 395, Dawbul, Genesee.
- Head fully bearded
  - Chaff white and smooth.
    - Grain red: Acadia, Canus, Coronation, Lee, Wasatch, Yogo.

Varieties of *Triticum durum* Desf.
- Head fully bearded, chaff red or brown and smooth, awns red or brown, grain amber: Carleton, Nugget, Stewart, Ramsey.

Discussion of Varieties

It is not proposed, in this section, to discuss the varieties of Table 1 in detail, but rather to indicate briefly their origin, the reasons for their distribution, and their performance and status.

Hard Red Spring Wheat for Manitoba and Eastern Saskatchewan

Thatcher wheat was developed at the Minnesota Agricultural Experiment Station in the U.S.A. from the double cross (Marquis × Iumillo) × (Marquis × Kanred). It was licensed in Canada in the autumn of 1935, a year when rust was epidemic and destructive, and released for seeding in the spring of 1936. At this time it was resistant to prevalent races of stem rust and loose smut but susceptible to leaf rust and bunt. It has a remarkably wide adaptation to both dry and moist conditions and is earlier maturing than Marquis. It was the leading wheat in Manitoba from 1939 to 1944; and has been the leading variety in Saskatchewan from 1939 to the present; and in Alberta from 1949 to the present.

Apex, developed at the University of Saskatchewan from the cross (H–44 × Double Cross) × Marquis, was licensed and released in the spring of 1937. Having resistance to stem rust but not to leaf rust, it was adapted only to an area in central Saskatchewan.

Renown and Regent, from the cross H–44 × Reward, and Redman, from the cross Regent × Canus, were developed by the group centred at Winnipeg, Manitoba. All three varieties were resistant to the four major diseases at the time of their release. Regent replaced Renown, and Redman in turn replaced Regent, because of higher yield and wider adaptation. Redman was the leading variety in Manitoba from 1951 to 1954 inclusive.

Craigie [12] estimated that, for the 5-year period 1939–43, the growing of rust-resistant wheat varieties in the 'rust area' (Manitoba and Eastern Saskatchewan) increased the average annual wheat production of that area by more than 40 million bushels.

Lee wheat was developed at the Minnesota Agricultural Experiment Station from the cross Hope × Timstein. It was licensed and released in the spring of 1950 because of its resistance to physiologic races of stem and leaf rust that had been prevalent up to that time. However, in July and August of the same year stem rust race 15B, to which Lee was moderately susceptible, became widely prevalent. Nevertheless, this variety, largely because of its resistance to leaf rust, gave higher yields than Redman in Manitoba, and continued to make a significant contribution to wheat production in the rust area of western Canada until 1955.

Race 15B of wheat stem rust, known to occur in the U.S.A. since 1939, and in Canada since 1946, was prevalent in both countries from 1950 onward. All wheat varieties released before 1953 were found to be susceptible to this race. Nevertheless, these varieties had served a useful purpose in the rust area until that time.

Selkirk wheat was bred by the group centred at Winnipeg from the backcross (McMurachy × Exchange) × Redman[3] to combat race 15B of stem rust and new virulent races of leaf rust. It was licensed in December

1953 and about 170,000 bushels of seed were released in the spring of 1954. The rust epidemic of that year was destructive to all varieties grown in the Prairie Provinces except Selkirk, and Canada's wheat production was reduced by an estimated 135 million bushels due to rust damage. The proportion of the wheat acreage sown to Selkirk wheat has increased rapidly in Manitoba and eastern Saskatchewan, and in the hard red spring wheat area of North Dakota, South Dakota, and Minnesota, in the U.S.A.

New races of stem rust capable of attacking Selkirk wheat have been discovered by the plant pathologists but these races have so far occurred with a very low frequency. Crosses have been made employing new sources of rust resistance such as the variety Kenya Farmer, from Kenya, East Africa, for stem-rust resistance, and Frontana, from Brazil, for leaf-rust resistance. New varieties, as yet unnamed, with resistance to the races of stem and leaf rust now known in Canada have been developed from this programme and are now in advanced stages of testing.

Hard Red Spring Wheats for the Drier Areas of Saskatchewan and Alberta

Thatcher (discussed above) was licensed in 1935 and has been the leading variety in the drier areas of the Prairie Provinces from 1939 to the present. Canus wheat, also licensed in 1935, was selected at the University of Alberta from material derived from the cross Marquis × Kanred made in 1908 at the University of Minnesota. Although high-yielding under dry conditions and resistant to bunt, it was inferior to Thatcher in yield and in resistance to shattering, and, consequently, was never grown as extensively as Thatcher. Lake wheat was developed at the Experimental Farm at Scott, Saskatchewan, from the cross Regent × Canus. It has considerable drought resistance and since its release in 1954 it has been grown mainly in the north-western part of the wheat area of Saskatchewan.

The two varieties having sawfly resistance combined with drought resistance are Rescue and Chinook. They were developed by the group centred first at Swift Current, Saskatchewan, and later at the Experimental Farm, Lethbridge, Alberta. The sources of the sawfly resistance were the solid-stemmed wheat S615 and a selection from it designated as S615–11. Rescue was developed from the cross Apex × S615, and Chinook from the cross Thatcher × S615–11. Chinook excels Rescue in test weight of grain and in milling and baking quality. In 1956 Rescue wheat was grown on about 1,000,000 acres, and Chinook on about 800,000 acres in the sawfly areas of Saskatchewan and Alberta.

Present work on the breeding of hard red spring wheat varieties for this area is concerned mainly with improved sawfly resistance, yield and quality, and resistance to the major diseases.

Hard Red Spring Wheat for the Northern Crop Areas of the Prairie Provinces and the Peace River Area of British Columbia

Thatcher became the main wheat in this area because it was earlier maturing and higher yielding than Marquis, higher yielding than

Reward, and of higher baking quality than Garnet. Saunders wheat, developed at the Cereal Crops Division, Ottawa, from the cross Thatcher × (Hope × Reward), was about three days earlier maturing than Thatcher and of about equal yielding ability. These two varieties now make up the bulk of the wheat crop in this region.

In 1949 the Experimental Farm at Lacombe, Alberta, became the co-ordinating centre for the 'Northern Wheat Breeding Project' with the objective of producing early maturing varieties for the northern regions. An important feature of this programme is the selection of plants under controlled greenhouse conditions to permit selection for such characteristics as superior root development, tillering habit, speed of growth, yield, and kernel size.

Yield of Hard Red Spring Wheats in the Prairie Provinces

A general measure of progress in breeding hard red spring wheats for the Prairie Provinces in the 25-year period of our review may be

TABLE 2. *Average Yields (bushels per acre) of Six Varieties of Hard Red Spring Wheat in the Prairie Provinces for the Six-year Period, 1952–7 (data from co-operative rod-row yield tests)*

Variety	I *Manitoba and black soil zones of Saskatchewan (seven stations each year)*	II *Brown and dark brown soil zones of Saskatchewan and Alberta (twelve stations each year)*	III *Black and grey soil zones of Alberta (four stations each year)*
Selkirk	43·2	32·3	50·0
Thatcher	38·1	32·8	52·2
Lee	40·4	31·1	45·4
Redman	38·1	30·3	48·2
Rescue	34·6	31·9	44·3
Marquis	34·6	30·5	46·4

obtained from Table 2, in which the yield results of six varieties in the six-year period 1952–7 are summarized. The data are compiled and summarized from the Co-operative Tests of Wheat Varieties conducted each year at twenty-three locations in the Prairie Provinces. Although the yields from such tests are higher than average farm yields, the relative yields of varieties correspond with those obtained under ordinary farm conditions.

The three Canadian wheats, Redman, Rescue, and Selkirk, were developed entirely within the 25-year period 1933–57. They are here compared with Marquis, the best Canadian variety before 1933, and with Thatcher and Lee, which were introduced from the United States.

Selkirk and Thatcher outyielded Marquis quite markedly in all three regions. In the rust area (Column I) Selkirk was clearly superior to all other varieties in yield. Even Thatcher, Lee, and Redman, though moderately susceptible to stem rust race 15B, yielded considerably more than Marquis in the rust area. In the drier region (Column II) Thatcher

yielded slightly more than Selkirk. However, the 6-year period of 1952–7 was, except for 1957, a period of above-average precipitation. With-average precipitation the yield of Thatcher would probably have exceeded that of Selkirk by a greater margin. In the Northern Region (column III) Thatcher gave the highest yields. Saunders, which was not included in this test, normally yields about the same as Thatcher even though it matures about 3 days earlier.

Soft White Spring Wheat for the Irrigated Areas of Southern Alberta

The soft white spring wheat variety Lemhi, developed at the Agricultural Experiment Station at Aberdeen, Idaho, from the cross Federation × Dicklow, was released in southern Alberta because of its marked superiority to the then leading variety, Dicklow, in yield, straw strength, and earliness. It was, however, extremely susceptible to stem and leaf rust. Lemhi 53 was developed at the same station from the backcross Kenya × Lemhi[5]. Both Lemhi and Lemhi 53 have good soft-wheat quality and the latter has moderate stem-rust resistance.

Breeding programmes with soft white wheat are under way both at Lethbridge and at the University of Alberta with the objective of developing high-yielding, high-quality varieties having stem-rust and leaf-rust resistance.

Winter Wheat for Southern Alberta

Kharkov M.C. 22 has, up to the present, been the leading hard red winter wheat in southern Alberta. Yogo wheat was developed at the Agricultural Experiment Station, Manhattan, Kansas, from the cross (Minturki × Beloglina) × Buffum. Though not quite equal to Kharkov M.C. 22 in winter hardiness and resistance to lodging, Yogo was released primarily for its superiority in resistance to bunt and to shattering.

Breeding programmes are in progress at Lethbridge and at the University of Alberta to develop winter wheats for both dry and irrigated land in southern Alberta. The main objectives are: increased winter hardiness; resistance to sawfly, smut, lodging, and shattering; improved quality; and higher yield.

Winter Wheat for British Columbia

Nearly all of the wheat varieties listed in Table 1, of both winter and spring types, have been grown to some extent in British Columbia because of the great diversity of growing conditions found in that province. We are here concerned, however, with three winter wheats used primarily in British Columbia. Sun wheat, the most popular variety on Vancouver Island, originated from a natural cross at the Svalöf Plant Breeding Station in Sweden. Ridit, developed from the cross Turkey × Florence at the Agricultural Experiment Station at Pullman, Washington, has been grown in the region of Armstrong, British Columbia, for its bunt resistance, but it has recently been attacked by new bunt races. Wasatch, from the cross Ridit × Relief, was developed at the Agricultural Experiment Station at Logan, Utah.

Having good resistance to both dwarf bunt and the ordinary bunt, it was also released in the Armstrong area. However, it has been grown there only to a limited extent because of its bearded characteristic and mediocre yield.

Durum Spring Wheat for the Southern Parts of the Prairie Provinces

The four durum wheats shown in Table 1 were developed at the North Dakota Agricultural Experiment Station at Fargo, North Dakota, from the crosses shown below.

Variety	*Cross*
Carleton	Vernal Emmer × Mindum[3]
Stewart	Mindum[3] × Vernal Emmer
Nugget	(Mindum × Carleton) × (Heiti × Stewart)
Ramsey	Carleton × P.I. 94701

All four had macaroni-making quality equal to that of Mindum, a requirement for the licensing of durum wheats in Canada. Carleton excelled Mindum in stem-rust resistance and strength of straw. Stewart, with similar rust resistance, was higher yielding and more widely adapted than Carleton. Nugget was released because of its early maturity, short straw, and high quality. However, its weak straw and susceptibility to stem rust soon led to its disappearance from extensive culture. Mindum, Carleton, Stewart, and Nugget proved to be highly susceptible to stem rust race 15B and their culture in Manitoba virtually ceased after the rust epidemic of 1954. The growing of durum wheat moved to Saskatchewan and Alberta. Ramsey, released for sowing in Canada in 1957, has effective resistance to most races of stem rust including the ordinary type of race 15B. However, it is quite susceptible to a subrace of 15B known as 15B4 (Can.) which, though not widely prevalent, has been fairly common in Canada for several years.

The rather limited durum wheat-breeding programme carried out at Winnipeg in the past has so far not produced a variety suitable for licensing. In view of the growing importance of durum wheat the scope of this programme was increased in 1956 with a wheat breeder devoting full time to durum wheat. The main emphasis is on the development of suitable varieties with resistance to the virulent races of stem rust. A backcross project has been initiated in which the high-quality, rust-susceptible varieties, Stewart, Mindum, and Carleton, are being used as recurrent parents in crosses with varieties having resistance to all stem rust races known in Canada. A number of varieties from Ethiopia are particularly promising. A longer-range project, in which the pedigree method is used, aims at the development of strains possessing high quality, stronger and shorter straw, and of earlier maturity than varieties grown at present.

Soft White and Soft Red Winter Wheats for Ontario

In 1933 Dawson's Golden Chaff (generally known simply as 'Dawson's') had been the leading winter-wheat variety in Ontario for about 40 years. In spite of its susceptibility to the major wheat diseases,

its strong straw, high yield, and good quality for production of soft wheat flour made it a difficult variety to excel.

The variety Rideau, produced at the Cereal Crops Division, Ottawa, from the cross Kharkov M.C. 22 × Dawson's was more winter-hardy than Dawson's but the grain was harder and less suitable for the production of soft-wheat flour. It has been grown in the eastern counties of Ontario where it has been used mainly for feed.

Cornell 595, a white wheat with somewhat better soft-wheat quality than Dawson's, was produced at Cornell University Agricultural Experiment Station, Ithaca, New York, from a series of crosses involving Honor (Dawson's), Forward, and Nured. It excelled Dawson's also in yield and in being resistant to loose smut. It soon became the leading wheat of Ontario although subject to shattering and sprouting.

Dawbul, a white-seeded wheat with resistance to shattering and loose smut, was developed from the cross Dawson's × Bulgarian at the Ontario Agricultural College, Guelph, Ontario. It yields about as well as Cornell 595 and is gaining in popularity.

Fairfield, a red wheat developed at the Agricultural Experiment Station, Purdue, Indiana, from the cross Purkof × Fulhio, has had only a limited use in the south-western counties of Ontario.

Genesee is a white wheat with good pastry quality from the cross [(Honor × Forward) × Honor] × Yorkwin made at the Cornell Experiment Station. Since it excels Cornell in yield and resistance to shattering, and has resistance to loose smut, it has now become the leading variety in Ontario.

Thorne, a red wheat produced from the cross Portage × Fulcaster at the Agricultural Experiment Station, Wooster, Ohio, has been grown to a limited extent in the south-western counties of Ontario, particularly Kent.

Richmond wheat was developed at the Cereal Crops Division from the backcross Dawson's^2 × Ridit. It excels the three main varieties (Genesee, Dawbul, and Cornell 595) in winter hardiness and has satisfactory soft-wheat flour quality. It is a high yielder, and, though susceptible to loose smut, is resistant to bunt (stinking smut) and moderately resistant to dwarf bunt.

The latest soft red winter wheat to be released is Kent, developed at the Ontario Agricultural College from the complex cross [Trumbull × (Hope × Hussar)] × Dawson's. It is distinctly superior to Fairfield in yield and disease resistance and has been released for the south-western counties of Ontario.

Spring Wheats for Eastern Canada

Coronation wheat, produced at the Cereal Breeding Laboratory, Winnipeg, from the cross Pentad × Marquis, and Acadia wheat, developed at the Experimental Farm, Indian Head, Saskatchewan, from the cross Canus × (Pentad × Marquis), were both hard red spring wheats originally bred for growing in western Canada. They were rust resistant and of exceptionally high yield, but were found to produce flour of slightly lower baking strength than Marquis. This disqualified

them for the higher commercial grades in western Canada, but they were found suitable for eastern Canada where spring wheats are used mainly for feed. An improved selection of Coronation wheat made at Ottawa was called Coronation II. Coronation, released in 1937, and Coronation II soon displaced Huron as the leading spring wheat in eastern Canada. Cascade is a high-yielding, soft to semi-hard white spring wheat which was developed at the Cereal Crops Division, Ottawa, from the complex cross [(Quality × Pacific Bluestem) × C–26–59–2D] × Onas, and licensed in 1947. It was gradually displacing Coronation when Acadia was released in 1951. Selkirk has given good yields through the eastern provinces and is on the list of recommended varieties. Selkirk and Acadia are now the most generally grown spring wheat varieties in eastern Canada.

Studies Related to Wheat Breeding

In this brief sketch it will be possible only to indicate in a general way the scope and results of representative investigations basic or related to wheat breeding carried out in Canada during the period 1933–57. While it will not be possible to deal with the many individual researches or to list the relevant publications, the writer will be pleased to supply, to those requesting it, a list of such publications.

There has been a tendency for much of the fundamental work on wheat to be concentrated in the Prairie Provinces, where the bulk of Canada's wheat is produced, and at the Central Experimental Farm at Ottawa, Ontario, which is the co-ordinating centre for the work of the laboratories and experimental farms of the Canada Department of Agriculture. In the Prairie Provinces fundamental work has been done by the three provincial universities, and by the laboratories and experimental farms of the Canada Department of Agriculture. In Manitoba, in addition, the Grain Research Laboratory of the Department of Trade and Commerce at Winnipeg has done much fundamental work on the quality of wheat.

As will be shown, aneuploid methods have furnished the basis of much of the cytogenetic research carried out on wheat in different parts of Canada. Canadian workers are indebted to Dr. E. R. Sears, University of Missouri, U.S.A., for his pioneer work in this field of wheat research.

Canada Department of Agriculture, Ottawa

The Cereal Crops Division of the Canada Department of Agriculture at Ottawa has had much success in developing plant-growth chambers particularly adapted for growing cereals. The growing of four generations of spring wheat or two of winter wheat per year made possible by this equipment speeds up the wheat-breeding programmes. Progress has also been made in developing improved small-scale methods of testing wheat for quality, enabling wheat breeders to eliminate low-quality material in early hybrid generations. The 'Expansion Test' requiring only 5 grammes of flour or wheatmeal is of particular value. Much cytological work was done on the earliest produced rust-resistant

wheats to determine the frequencies of various chromosomal aberrations and thus assist plant breeders in selecting stable foundation lines. One cytological study, for example, disclosed that the repeatedly occurring white-chaffed mutant in Dawson's Golden Chaff winter wheat was due to the loss of an arm of a particular chromosome.

The Botany and Plant Pathology Division has recently undertaken a much-needed comprehensive taxonomic study of Triticum, Agropyron, Aegilops, and Hordeum.

The Grain Research Laboratory, Winnipeg

The factors determining quality in both bread wheats and durum wheats have been studied in great detail. It was shown, for example, that the rate of loss of pigment from durum semolina during the mixing of macaroni dough was dependent upon the amount of the enzyme lipoxidase present in the durum wheat. Established methods and equipment for testing wheat for quality were improved to increase both the speed and accuracy of testing. New tests were developed, particularly employing small quantities of wheat. As early as 1935 a mill for milling as little as 100 grammes of wheat was developed, and baking techniques employing 25-gramme doughs indicated that the so-called micro milling and baking techniques gave results agreeing closely with those of standard laboratory techniques. Much of the necessary equipment for new or improved techniques in micro and standard tests was designed and built at this laboratory.

Canada Department of Agriculture Research Laboratories, Winnipeg, Manitoba

The Cereal Breeding Laboratory and the Plant Pathology Laboratory at Winnipeg have co-operated in fundamental work on wheat and its main diseases, of which only rust will be considered here. Cytologic studies of the wheat-stem-rust organism (*Puccinia graminis tritici* Eriks. and Henn.) showed it to have six chromosomes in the haploid phase. Genetic studies of the same organism showed that the visible characters of spore colour and the physiological characters of pathogenicity are inherited in a Mendelian manner. Annual collection and identification of rusts detected new races and subraces of stem rust and leaf rust, thus providing a sound basis for breeding wheats resistant to races likely to become prevalent. Johnson [13] has reviewed researches on the rusts of cereals up to 1952.

Genetic studies in wheat in 1939 and 1940 showed that the three rust-resistant wheats, McMurachy, Kenya R.L. 1373, and Red Egyptian, each had a main gene for resistance to the then known races of stem rust, and that these genes were allelic. This information furnished a basis for the breeding of Selkirk wheat. The two wheat varieties from which Selkirk derived its stem-rust resistance, namely, McMurachy and Redman, were studied by monosomic methods, which showed the main gene for resistance in McMurachy to be located on chromosome XX, and three genes for resistance to stem rust race 56 in Redman to be on

chromosomes III, VIII, and XIII, respectively. A complete set of twenty-one monosomic lines was developed in Redman wheat. A 56-chromosome rust-resistant perennial wheat was developed from the backcross Chinese^2 × Agropyron *elongatum*, the parental types having forty-two and seventy chromosomes, respectively. A chromosome segment carrying a gene for stem-rust resistance was translocated by means of irradiation from an Agropyron derivative of the above type to Redman spring wheat. An improved scale for determining the degree of rust infection on plants was developed.

Studies on the nature of rust resistance and on host-parasite relations in wheat have been conducted in recent years. For example, the reaction of normally rust-resistant plants has been altered from resistant to susceptible by several environmental and chemical means, and the accompanying metabolic changes in the wheat have been followed by means of chemical analyses.

A self-contained growth cabinet for plant-breeding purposes was developed, and the recent commercial production of this cabinet has contributed significantly to the speeding-up of wheat-breeding work in Canada.

The University of Manitoba

Until 1954 plant-breeding work at the University of Manitoba was for the most part concerned with crops other than wheat. However, in that year a very comprehensive programme of fundamental research in wheat and its relatives was begun, and promising results in several lines of work have already been obtained. A large collection has been made of species of the genera Triticum, Aegilops, Agropyron, Secale, and Haynaldia and of artificially synthesized species from various countries. New combinations of genomes have been made by crossing different species, and doubling the number of chromosomes in the hybrids by treatment with colchicine. Particular attention has been given to combining the AB genomes of durum wheat with various other genomes. One of the most promising new species developed in this way is one with forty-two chromosomes, derived from Stewart durum wheat and a fourteen-chromosome type of *Agropyron elongatum*. Rust-resistant durum wheats have been obtained through the irradiation of seeds of the Stewart and Nugget durum varieties.

A complete series of monosomic lines has been developed in Kharkov M.C. 22 winter wheat. Chromosomes of a self-fertile strain of winter rye (Dakold) have been added to Kharkov winter wheat to increase its winter hardiness. Some 'addition lines' possess all twenty-one pairs of chromosomes of the winter wheat and a specific pair of winter rye chromosomes. This material is being further used to develop 'substitution lines', each having twenty pairs of wheat chromosomes and one pair of rye chromosomes.

Various sets of isogenic lines have been developed, for example, two strains of Lee wheat differing only in one being awned and the other awnless. These are being used in a study of the effect of awns on yield and other quantitative characters.

The University of Saskatchewan

Basic studies were made on methods of assessing resistance to spring frost injury, lodging, shattering, seed bleaching, and sprouting in wheat. For example, a good index of resistance to lodging was obtained by washing the soil from a sample of plants and counting the crown roots.

Comprehensive studies have been made of the inheritance of the resistance to stem rust races 56 and 15B possessed by the main wheats being used by Canadian wheat breeders as sources of rust resistance. Diallel crosses of resistant varieties were made to determine which varieties carry the same genes; and each resistant variety was crossed and backcrossed to Marquis (the latter being the recurrent parent) for a genetic analysis of rust resistance. Eighteen rust-resistant varieties have been thus analysed genetically, and the individual genes are being isolated in the Marquis genotype. In several cases the chromosomes carrying the genes for rust resistance have been identified by monosomic methods.

Further selection was made in the rust-resistant perennial wheat from Chinese[2] × *Agropyron elongatum* developed at Winnipeg, and selected lines were released to plant breeders in various countries. The stem-rust resistance of *A. elongatum* was transferred to common wheat by means of irradiation, presumably through the transferring of a small piece of *Agropyron* chromatin to a wheat chromosome.

In other irradiation experiments radioactive phosphorus (P^{32}) was supplied to germinating seeds, seedlings, and young plants of wheat. Fifteen recognized mutants were obtained in common wheat, and a number of these gave rise to progeny having new phenotypes, some of which bred true. Most of the phenotypic changes appeared to be due to changed gene balance rather than to gene mutation.

Tracer techniques together with more conventional methods of physiology have been used to study host-parasite relations in wheat. It was found that accumulation of various carbon compounds in wheat leaves at sites of infection by rust and mildew in general paralleled the time course of respiration, and was in fact dependent on aerobic respiration, which is markedly increased in infected tissues. There was no concomitant stimulation of CO_2 evolution under nitrogen. The pattern of respiration indicated a marked shift in carbohydrate metabolism to the pentose-phosphate pathway in infected tissue. The relation of auxins and antiauxins to carbohydrate metabolism and to infection of wheat leaves by rust and mildew has also been investigated.

The Experimental Farm, Swift Current, Sask.

A collection of solid-stemmed wheats was made and it was shown that sawfly damage in wheat could be greatly reduced by growing solid-stemmed varieties. Genetic studies demonstrated that stem-solidness in certain bread wheats was dependent upon three pairs of recessive genes. Environmental factors affecting sawfly resistance in wheat were studied. All of this work was transferred to Lethbridge, Alberta, in 1948.

The Canada Department of Agriculture Laboratories, Lethbridge, Alberta

The studies carried out at Swift Current up to 1948 were continued and greatly extended at Lethbridge by the Cereal Breeding Laboratory of the Experimental Farm together with the Plant Pathology and the Field Crop Insects Laboratories. In studies of sawfly resistance in wheat, it was found (1) that sawflies showed oviposition preferences for certain varieties; (2) that survival of the eggs of the first instar larvae and of the later instars was reduced by stem solidness, but the effect of the pith varied with environment. The durums were more resistant to egg hatch than were the bread wheats. Stem solidness was the only single morphological character that gave a measure of overall sawfly resistance.

In a remarkable series of cytogenetic researches employing aneuploid and chromosome-substitution methods in wheat, chromosomes carrying genes affecting the development of pith in the stems were identified. In the solid-stemmed variety S615, for example, it was shown that chromosomes III, V, IX, XVI, and XVIII carry genes tending to produce pith in the stems, and that chromosomes XIX, XX, and XXI carry genes tending to decrease pith development. In the hollow-stemmed wheat Chinese Spring, on the other hand, it was shown that chromosome VIII tends to promote development of pith and that chromosomes II, XIII, XIX, XX, and XXI have genes tending to decrease pith development.

A successful method of testing winter wheats for cold hardiness in the sprouted-seed stage in a controlled-temperature freezing chamber was developed, permitting the rapid testing of large numbers of varieties or hybrids in a small space.

Methods of control of wheat-stem sawfly other than the use of resistant varieties have been investigated, for example, the use of parasitic insects, insecticides, and cultural methods.

The University of Alberta

In addition to breeding hard red spring wheats for drought resistance, soft white spring wheats for resistance to stem and leaf rust, and hard red winter wheats for winter hardiness, the Plant Science Department of the University of Alberta has conducted a comprehensive programme of fundamental research in cytogenetics of wheat and wheat relatives. Much of this programme has been based upon aneuploid and chromosome-substitution methods, and only a few examples of the many published results can be mentioned here.

By means of the above-mentioned methods chromosome pairs of Chinese Spring wheat were separately replaced by the corresponding chromosome pairs of Thatcher wheat so as to develop substitution lines each having a known pair of Thatcher chromosomes and twenty pairs of Chinese Spring chromosomes. Similar sets of substitution lines of Chinese Spring wheat with chromosomes from the donor varieties Hope and Timstein were developed. Appropriate tests of each member of the three sets of substitution lines indicated which chromosomes carried genes conditioning awning, earliness, height, lodging, protein content, spike density, 1,000-kernel weight, and yield. The reciprocal substitu-

tion of each pair of chromosomes of Thatcher and Lemhi is nearing completion. Since these two varieties have contrasting quality characteristics, the lines with reciprocal chromosome substitutions will furnish a basis for studying the genetic components of quality.

Chromosome XX from McMurachy wheat, with its gene for rust resistance, has been substituted for its homologous chromosome in the Thatcher and Lemhi varieties. The same process has been carried out with chromosome X carrying a gene for rust resistance from Timstein wheat.

Other Centres

Important fundamental researches on wheat have been conducted at other centres including the Ontario Agricultural College, the University of Toronto, and Macdonald College of McGill University. Some of these investigations have been less closely related to the main problems of wheat breeding than the work reviewed above, and they cannot be dealt with here for reasons of space.

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ADVANCES IN PLANT BREEDING AND GENETICS IN RELATION TO CROP IMPROVEMENT IN INDIA IN THE LAST TWENTY-FIVE YEARS

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WITH PLATES 3, 4, 5

THE establishment of the Indian (then Imperial) Agricultural Research Institute at Pusa in Bihar (now located in New Delhi) and of Departments of Agriculture in the various provinces of India, in the beginning of the present century, marked the commencement of organized research in plant breeding in this country. Albert Howard in wheat, D. Milne, G. A. Gammie, and H. M. Leake in cotton, G. P. Hector in rice, and C. A. Barber and T. S. Venkataraman in sugar-cane are remembered even today as being the pioneers in this field. The primary objective of the researches before 1933 was improvement in yielding ability and quality and the methods employed mainly consisted of the exploitation of natural variability in crop plants within the country and, to some extent, selection in segregating progenies of intervarietal hybrids; in this way a number of improved varieties were produced in the major food and industrial crops of the country. As ancillary to plant-breeding work genetical studies were undertaken in rice, cotton, millets, wheat, and in several other crops and the mode of inheritance of numerous plant characters was worked out.

During the period, 1933–57, covered by the present review, plant-breeding activity expanded considerably. Basic problems such as breeding for resistance to diseases, pests, and adverse conditions of soil and climate, as well as problems of local and regional importance, such as the breeding of varieties suited to special conditions, e.g. flooding, soil salinity, and droughtiness, received increasing attention. To this end researches in cognate sciences such as cytogenetics and plant physiology and in the fields of plant introduction, induction of polyploidy and mutation, exploitation of heterosis, and distant hybridization were increasingly brought to bear.

India grows a large variety of economic plants under very varying conditions of soil and climate. It is, therefore, an obviously difficult task to include in such a brief review as this an account of all that has been done in the field of plant breeding in this country during the past 25 years. Hence, only a broad survey of the various problems and of the results achieved in the breeding of important groups of crops will be attempted here.

Cereals

Rice. Rice, which is the most important cereal crop in India, covers about 77 million acres and is grown under diverse conditions in areas subject to floods and salt-water inundation, or characterized by soil

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alkalinity and drought. Fungal diseases caused by *Piricularia oryzae* (blast); *Helminthosporium* sp., *Cercospora oryzae* (leaf spot), and *Fusarium moniliforme* (foot rot), insect pests such as the stem borer *Schoenobium incertellus*, rice bug (*Leptocorisa varicornis*), and the swarming caterpillar (*Spodoptera mauritia*) take a considerable toll of the crop. Breeding work has resulted in the evolution of a full range of improved varieties suited to individual tracts or to special conditions of growth; varieties with wider adaptability, such as GEB24 in Madras, have also been bred. From the cross *Oryza sativa* GEB24 × *O. longistaminata* (wild), a drought-resistant strain has been evolved. Salt-resistant types, e.g. Harai and SR 26B, were bred in Bengal and Orissa respectively. Several strains of deep-water paddy, e.g. Maitching 834 and Kala Aman 809, which can grow in 13–14 feet of water, were evolved in Bengal.

Blast is the most serious among fungal diseases. In Madras the strain Co.4 was found to be highly resistant. By using this strain in hybridization work, a number of new blast-resistant strains have been produced in Madras. Similar work has been done in Bombay, Andhra, Orissa, and Bihar. Extensive screening done at the Central Rice Research Institute, Cuttack, has shown about nine indigenous and fifty exotic strains to be resistant to blast. In breeding for resistance to the rice bug, Sathi, a variety in which the panicle remains enclosed in the sheath was sought, to be utilized in breeding. In the case of the stem borer, varietal resistance depending on the mechanical tissue structure of the stem has been noticed.

The wild-rice problem has been successfully tackled by breeding anthocyanin pigmentation into improved varieties. A recent fruitful line of work, being done at the Central Rice Research Institute and several States, is the utilization of crosses between the *indica* and *japonica* races of *O. sativa*, to incorporate non-lodging habit, non-shattering of grain, and high response to nitrogen fertilizers, from the latter race to the former. Already the work has yielded several promising selections [1]. (See Fig. 3, Plate 4.)

As a result of extensive genetical studies more than 300 genes affecting about fifty plant characters have been recognized and their inheritance followed. Several mutant genes have also been located; from X-irradiation of GEB24, a better-tillering and finer-grained isolation was obtained in Madras. Recent cytological studies have suggested that *O. perennis*, which occurs both in India and Africa, is the ancestral form of cultivated rice. Ramiah, in a monograph [2], has fully dealt with the work done in India on the breeding and genetics of rice.

Wheat. About 27 million acres are put under wheat in India annually. *Triticum aestivum* is the most extensively grown species; other species cultivated are *T. durum* and *T. dicoccum*. Nearly 66 per cent. of the wheat area is rainfed; breeding for drought resistance is therefore important.

Up to the thirties, several better-yielding good-quality wheats had been bred to suit the varying conditions in the wheat-growing tracts. But the task of combining these attributes with disease resistance remained to be tackled. Among the fungal diseases of wheat, the three

rusts are by far the most destructive, causing an annual loss of about Rs. 60 million. Other important fungal diseases are loose-smut (*Ustilago tritici*), stinking smuts (*Tilletia foetida* and *T. caries*), and Karnal bunt (*Neovosia indica*); Alternaria and Helminthosporium have recently assumed importance in some areas. The pioneering researches of the late Dr. K. C. Mehta brought forth, during the early thirties, the first authentic knowledge regarding the occurrence of physiologic races in the cereal rusts in India. This greatly facilitated the undertaking of planned work for breeding rust-resistant wheats. Work in this field was initiated at the Simla Substation of the Indian Agricultural Research Institute and later extended to Delhi and Pusa. Today eleven races and three biotypes of black rust, nine races of brown and ten of yellow rust are recognized. Several hundred collections, exotics and indigenous, were screened under controlled conditions for resistance to the different physiologic races, and suitable wheats among them such as the Kenya wheats, Spaldings Prolific, Democrat in the early years and Frontiera, Rio Negro, Timstein, and Gaza (*T. durum*) recently, were used as donors of resistance. As a first step a number of highly successful wheats (N.P. 710, N.P. 718, N.P. 770, and some others), tolerant to rust and highly resistant to loose smut, were bred and released for cultivation. Subsequently, strains separately resistant to each of the rusts were built up. Lastly, through complex crosses, combined resistance to two or all of the three rusts, besides high resistance to loose smut, was achieved. The strain N.P. 809, an outcome of 18 years of collaborative work between plant breeders and plant pathologists, is a landmark in the history of wheat breeding in India, combining as it does a very large measure of resistance to all the three rusts occurring in this country [3, 4, 5]. Recently work on these lines has progressed in the Punjab also, and in Madhya Pradesh and Bombay black-rust-resistant wheats have been evolved. Current breeding work aims at further improvement as regards yield, disease resistance, and nutritive qualities including milling, baking, and *chapatee*-making qualities, for which a laboratory on modern lines is being set up at the Indian Agricultural Research Institute. Information has been gathered on the genetics of several plant characters [6] including rust resistance [7] and these studies are being supplemented by monosomic analysis of various characters [8]. Intergeneric and interspecific hybridization has been undertaken for cytogenetical studies and for breeding for disease resistance. Several interesting mutations, affecting awn and other characters, and cytological effects have been obtained at the Indian Agricultural Research Institute using radioactive isotopes, neutrons, X-rays, and certain oils as mutagens [9] and results potentially useful in breeding work have accrued from plant physiological studies on plant nutrition, resistance to lodging, and drought. (See Figs. 1, 2, 5, Plates 3 and 5.)

Barley. Prior to 1933, two very successful varieties, N.P.13 and N.P. 21, were bred at the Indian Agricultural Research Institute. Since barley is a collateral host of the black and yellow rusts of wheat, breeding for resistance to rust, smuts, and Helminthosporium was initiated a few years back at Delhi and Simla. Breeding for special qualities, e.g.

suitability for malting and pearling, is also in progress. Barley breeding also made considerable progress in the States of Uttar Pradesh and Punjab.

Maize. Maize is grown both in the hills and plains of India and covers 9 million acres. Locally adapted, mass-selected bulks have been in cultivation. Realizing the industrial potential of this crop and the success achieved by hybrid maize in other countries, work on these lines was commenced some 10 years ago at New Delhi, in Bombay, and in the Punjab; subsequently work was also commenced in other areas. As a first step, a number of foreign dent-maize hybrids were tried out in representative maize-growing tracts and some of them, e.g. N.C. 27, U.S. 13, Dixie 22, and Texas 26, gave 20 to 40 per cent. more yield than local varieties. Flint maize is, however, preferred in India to dent, and recent breeding work has resulted in the production of the double-cross, Punjab Hybrid I, in the Punjab and a three-way hybrid, (I.5 × L.5) × S.23, in Bombay. These hybrids yield about 20 per cent. more than the local varieties and they are being distributed to farmers on a limited scale. At the Indian Agricultural Research Institute dent × flint crosses, yielding semi-dent grain, have been found to be 40–80 per cent. more productive than the best locals. Very recently, hybrid-maize work has been more fully co-ordinated on a regional basis and extensive collections of foreign inbreds have been made to impart further genetic diversity. The problem of producing high-yielding synthetic varieties is also receiving attention. Recently, some inbred lines have appeared to possess marked resistance to the stem borer (*Chilo zonellus*) which is a most serious pest of maize and sorghum in India [10].

Millets

This group of hardy smaller-grained cereals collectively occupies 80 million acres of predominantly rainfed land. Although sorghum and pearl millet (*bajra*) are the two major millets, several other millets such as Finger Millet, Italian Millet, Kodo Millet, and Proso Millet are also commonly grown in India. In these crops, varieties are believed to exhibit highly localized habitat preferences markedly. In sorghum, the stalks are as important to the grower as the grain and therefore varieties giving high grain yield and also good harvest of dry stalks are preferred; besides, purely fodder varieties of sorghum are also in demand and have been bred. Breeding for adaptation to local conditions, therefore, assumes much importance. Fifty years' breeding work has resulted in the production of several improved varieties, a large proportion of them in the States of Madras and Bombay [11, 12, 13]. Inbreeding work has been carried out in the pearl millet and the phenomenon of protogyny has been taken advantage of for large-scale production of hybrid seed. In both Madras and Bombay hybrid pearl millet has given 25–40 per cent. higher yields than the commonly grown crop. Hybrid vigour has been observed in sorghum in Bombay State and work is under way to utilize male-sterile lines for commercial hybrid-seed production. Attention has also been given to breeding for resistance to Striga [11, 12]. A considerable amount of genetical work has been carried out, especially

in sorghum [14]. Cytogenetical studies have shown that the para-sorghums, contrary to belief, have appeared not to play a role in the evolutionary origin of cultivated sorghum [15]. Desirable characters, such as perennial habit and profuse tillering, have been incorporated into cultivated sorghum from the wild *S. halepense* [16]. The wild species, *Pennisetum purpureum* ($2n = 28$) and the cultivated pearl millet (*P. typhoides*, $2n = 14$) were shown to possess one genom in common.

Pulses

This is a group of leguminous crops, comprising gram (*Cicer arietinum*), pigeon pea (*Cajanus cajan*), green gram (*Phaseolus aureus*), black gram (*P. mungo*), lentil (*Ervum lens*), and other minor crops, which figure prominently in crop rotations and crop mixtures practised by the farmers for maintenance of soil fertility. Breeding for earliness, high yield, and better protein content and cooking quality of grain has resulted in the production of a large number of varieties suited to the different tracts. In breeding for disease resistance, attention has been given to the wilt diseases of pigeon pea, where some highly wilt-resistant strains have been bred at this Institute and in Bombay, and to a lesser extent of Bengal gram and *khesari* (*Lathyrus sativus*). In the Punjab, two strains of gram, F.8 and 62–18, were reported to be resistant to blight (*Mycosphaerella rabiei*). It was also found in gram that varietal resistance to the cutworm bore a remarkable relationship with the anatomical structure of the stem.

Inheritance of a number of plant characters has been worked out [17]. Autotetraploids produced by the colchicine technique did not prove to be economically useful owing to pronounced seed sterility [18]. There is yet considerable scope in these crops for breeding for resistance to pests and diseases, for the improvement of cooking quality, protein content, and other nutritive qualities, for special qualities like parching and canning, increased vegetative vigour for forage purposes, and capacity for better fixation of nitrogen.

Oilseeds

India is a principal oilseed-producing country of the world with an area of 29 million acres under oilseed crops. The major crops, in the order of their acreage are: groundnut, rape and mustard, sesame, linseed, castor, niger, and safflower. During the first three decades, considerable work was carried out on the isolation of types from indigenous material and a number of improved strains in the major crops were released. John [19] has presented a good review of research work done on oilseeds in India.

Groundnut. In breeding work, the emphasis has been on yield, plant habit, early maturity, increased shelling percentage and oil content, and dormancy of seed. Bunchy types are early maturing and easier to harvest, but their seeds are non-dormant. Dormant seed habit has been incorporated into them by crossing them with late spreading types; the strain AH 6481, bred in Madras, is an instance in point. The leaf-spot disease, caused by Cercospora, is an important disease to which

bunchy types are more susceptible than the spreading ones. By suitable hybridization, some fairly resistant bunchy types, such as H.G.1, have been bred. The wild species *Arachis rasterio* has appeared to be a useful source of Cercospora resistance. Other problems engaging attention include improvement of oil content by use of some foreign groundnut varieties, and resistance to other diseases and pests.

Rape and mustard. Species of Brassica, and *Eruca sativa*, are extensively grown for oil in the Gangetic alluvium, mostly mixed with other crops and sometimes in monoculture. They are predominantly outpollinated and some, like the Indian rape (*B. campestris* var. *toria*), brown *sarson* (*B. campestris* var. *dichotoma*), black mustard (*B. nigra*), and *E. sativa* are self-incompatible; in these mass selection has been done in Punjab and Uttar Pradesh, whereas in the Indian mustard (*B. juncea* and *sarson* (*B. campestris* var. *Sarson*) improved types have been bred through individual plant selection. At this Institute, the colchicine-induced autopolyploids have been successful [18]. Ramanujam and Srinivasachar [20] experimentally synthesized *B. juncea* ($n = 18$) from the elemental species *B. campestris* var. *toria* and *B. nigra*.

Sesame. In this crop several improved strains have been built up through individual plant selection. Important breeding problems are: non-shattering nature of capsule, high yield and oil content, resistance to drought, to phyllody, leaf curl, and *Macrophomina phaseoli* diseases, and to the insect pest, *Antigastra catalaunalis*. In breeding for resistance to phyllody caused by a virus, use had been made of the wild *Sesamum prostratum* ($n = 16$) as the donor.

Linseed. This is one of the most important industrial oilseeds of India, in which several improved types have been bred. The rust (*Melampsora lini*) problem has been overcome through the production of resistant types at the Indian Agricultural Research Institute and in the Punjab; some of these strains are resistant to wilt also, which is another serious disease. Other problems are: breeding for high yield, boldness of seed, increased oil content and iodine value, and resistance to powdery mildew and the insect pest—*Dasyneura lini*.

Castor. This crop has received much attention mainly in Hyderabad (now Andhra), Madras, and Bombay where improved varieties have been made. Some types with 55–57 per cent. oil have been bred in Hyderabad. Hardiness, resistance to drought, and early maturity are important breeding problems. Some American castor hybrids were recently being tested for performance.

Safflower and niger. These are relatively minor oilseeds. Improved types of safflower have been bred at Pusa and in Uttar Pradesh, Bombay, Hyderabad, and Madras; some Nebraska strains showed markedly high oil content. N.P.30 is a good, non-spiny fodder type. Improvement of niger has been carried out in Madhya Pradesh.

Fibre Crops

India grows a large variety of vegetable fibres, cotton and jute being the most important among them. Other fibre crops include kenaf (*Hibiscus cannabinus*), roselle (*H. sabdariffa*), sannhemp (*Crotalaria*

juncea), agave (*Agave* spp.); coir from the coconut is also important.

Cotton. The present area under cotton in India is about 20 million acres with an annual production of about 4 million bales. The diploid species, *Gossypium arboreum* and *G. herbaceum*, have been in cultivation from ancient times, whereas *G. hirsutum* was introduced from the New World in the eighteenth century. The Indian Central Cotton Committee, formed in 1921, has played an important role in the financing and co-ordination of cotton research in India.

Cotton is grown under widely different soils and climates in this country; a large proportion of the area, being rainfed, is liable to periods of drought. The indigenous cottons thrive better in such areas, whereas *G. hirsutum* does well only under irrigation or assured rainfall. Adaptations to local conditions and conjoint improvement in yield, ginning out-turn, staple length, and spinning quality have been the principal objectives in breeding work in all the three species; in *G. hirsutum* some outstanding selections, e.g. Co.2, Gadag, and 4F, were made from acclimatized material. By 1933 about 25 per cent. of the area was grown to improved types and about 75 per cent. of the country's production was of short staple ($\frac{11}{16}$ in. or below). Progressively the area under medium ($\frac{23}{32}$–$\frac{27}{32}$ in.) and long ($\frac{7}{8}$ in. and above) stapled cottons increased, improved types of *G. hirsutum* having contributed considerably to this process. At present, only 23 per cent. of the country's output is of short staple. In *arboreum* and *herbaceum*, varieties possessing a staple length of nearly 1 in. and capable of spinning to counts as high as 37 to 42 have been released. In *hirsutums* the corresponding values reached are about 1 to $1\frac{3}{16}$ in. for staple and up to 52's for spinnability [21]. Some of the most outstanding varieties are, *arboreum*: N.14, Gaorani 6, and Virnar; *herbaceum*: Jayadhar and Vijalpa; *hirsutum*: MCU-2, H.14, 134 Co.2-M. These strains of *arboreum* and *herbaceum* are highly resistant to Fusarium wilt and represent the culmination of successful work in this direction. In the *hirsutums*, breeding for blackarm resistance is in progress; success has also been achieved in the evolution of jassid-resistant types, but the problem of boll-worm resistance is yet unsolved. Work has been done, especially at Surat and Coimbatore, on interspecific hybridization. (See Fig. 6, Plate 5.) Heterosis in *hirsutum* × *barbadense* hybrids is being sought to be commercially exploited. Comprehensive genetical studies have been undertaken. Hutchinson and Panse [22], working with cotton, formulated the noted replicated progeny-row technique which has since been used in the breeding of this and many other crops. India is still deficient in cottons of more than 1 in. staple. This, apart from improvement in yield and breeding for resistance to pests and diseases, constitutes one of the most important lines of present and future work on cotton in India. Researches on induced mutagenesis have also been taken up at the Indian Agricultural Research Institute.

Jute. Jute is one of the most important industrial and export commodities. In 1947 a substantial portion of the jute acreage, and the Jute Research Laboratory established in Dacca in 1938, went to Pakistan. Since then research is in progress on jute and other fibre crops at the Jute Agricultural Research Institute, established anew in 1948 near

Calcutta. In both *Corchorus olitorius* and *C. capsularis*, grown in India, improved varieties have been bred and genetical work carried out [23, 24]. The main objectives are improved yield and fibre quality; anatomical and physiological studies have also been in progress for formulating suitable selection indices for fibre yield and quality during the growth of the plant. Hybridization between *olitorius* × *capsularis* has been attempted for combining desirable qualities of both these species; but early abortion of the hybrid embyro seems to be responsible for failure of the cross. The problem of breeding for resistance to diseases and pests is also receiving attention.

Kenaf and roselle. Breeding work on these crops, which are at present gaining importance as jute substitutes, began early in this century and several improved types were evolved at the Indian Agricultural Research Institute prior to 1933. Further improvement work through hybridization is in progress. Roselle gives heavier fibre yields than kenaf but is late; breeding for early maturity is therefore an important problem.

Sannhemp. Early breeding work in this crop resulted in the selection of many improved varieties. The problem of seed setting also received attention. Breeding for resistance to wilt and to the top-shoot borer has been carried out [25]; breeding for resistance to other diseases and pests, as also further work for improvement of yield and fibre quality, is under way.

Vegetables

India grows a wide variety of tropical and temperate vegetables. Prior to 1933 little breeding work was done in these crops. Until World War II, seeds of the temperate vegetables had to be largely imported from abroad. Only recently these seeds have been produced first at Quetta and later in Kulu and Kashmir valleys.

Potato. Breeding work on this important vegetable crop, extensively grown in the hills and plains of India, first commenced at Simla under this Institute in 1935, where a comprehensive collection of varieties and wild species was built up and utilized for the production of many improved varieties [26, 27]. Breeding for resistance to late blight and charcoal rot has also been in progress and a seed-certification programme is also being worked out by the Central Potato Research Institute, Simla, established in 1948, in co-operation with the important potato-growing States. Genetical work on the self-incompatability mechanism has also been done [27].

Other vegetables. At the Indian Agricultural Research Institute extensive collections of indigenous and exotic material were assessed. Several promising strains were developed by simple selection in this material. A consolidated account of the varieties so evolved has been given by Pal *et al.* [28]. A small-fruited salad-type tomato—Pusa Red Plum—rich in sugar and vitamin C was selected from the cross *Lycopersicum esculentum* × *L. pimpinellifolium*. An early-ripening hardy autumn variety of tomato named Pusa Ruby was bred from the cross Sioux × Meeruti.

Genetical and cytogenetical investigations carried out in a few vegetables include the inheritance of sex forms such as monoecious, andromonoecious, gynoecious, and hermaphrodite in *Luffa acutangula*. Joshi and Hardas [29] produced evidence for the allopolyploid origin of Lady's finger (*Abelmoschus esculentus*, $2n = 130$), the wild 29-chromosome species, *A. tuberculatus* Pal & Singh, being one of its putative ancestors.

Exploitation of hybrid vigour in vegetables also received attention in brinjal and bitter gourd. Recently similar work has been done on tomato and okra and use is being made of genic male sterility for hybrid-seed production in tomato and of cytoplasmic male-sterility in onion. At the Vegetable Breeding Station at Kulu valley improvement of temperate vegetables has been taken up.

Fruits

India grows a large variety of fruits—both tropical and temperate. Mango is considered to be the king of them all and in this selection work in historical times has yielded several distinct *élite* varieties. It is, however, true that in India the breeding of fruit trees has until recently not received as much attention as have the cultural aspects of fruit cultivation, although some amount of classificatory and cytological work has been done in recent years on mango, banana, papaya, and zizyphus. Recently, however, the improvement of fruits by genetic methods has been taken up at several centres throughout the country.

Plantation Crops

Sugar-cane. After the release, in the late twenties, of the first batch of Coimbatore canes which gained popularly particularly in the northern sub-tropical parts of the country, the objectives in sugar-cane breeding have been the evolution of high-yielding varieties capable of withstanding drought, frost, and waterlogging and of resisting diseases and insect pests. A wide range of maturity period is also desirable so as to extend the crushing season.

Extensive use was made of a wide range of parents for intervarietal, interspecific, and intergeneric hybridization. Most of the present-day canes in India have genic contribution from *Saccharum spontaneum* and *S. barberi* as also from the 'noble' canes such as 'Villai'. As part of this programme explorations were undertaken for collecting various forms of *S. spontaneum*, Erianthus, and Narenga, possessing drought and frost resistance. Dutt [30] has reviewed the varietal position of Co. canes in the various sugar-cane-growing States of India; outstanding among these are Co.419, Co.421, Co.527, Co.617. Khanna *et al.* [31] have discussed the usefulness of canes bred in Bihar for combining resistance to red rot with high tonnage and high sucrose.

As a result of cytological studies of intergeneric hybrids, Parthasarthy [32] concluded that five of the chromosomes of *Sclerostachya fusca* ($2n = 30$) are homologous with five of the basic chromosome set ($n = 10$) of *S. officinarum*.

In recent years, the world collection of sugar-cane and allied species

maintained at the Sugarcane Breeding Institute, Coimbatore, has been considerably augmented.

Coconut. Research on coconut has been in progress since 1916 but it was only in the early forties that extensive intra- and inter-varietal hybridization was taken up with a view to breeding for regular bearing habit, larger nuts, and good-quality copra with high oil content. Considerable heterosis was observed in tall and dwarf hybrid combinations. Some useful varieties like San Ramon were introduced from the Philippines and Borneo. Coconuts of Laccadive Islands were found to show a low shedding of 'buttons' and high oil percentage and appeared useful as breeding stocks. In recent years attention has been given at the Central Coconut Research Institute, Kasargod, to breeding for resistance to important diseases and pests.

Coffee and tea. Researches on these crops have been in progress under the aegis of the Indian Coffee Board and the Indian Tea Association respectively, the principal research centres being Balehonnur in south India for coffee, and Tocklai in Assam for tea.

Improvement work on coffee commenced in India in the first quarter of this century, the principal objective being yield, larger bean size, resistance to leaf disease caused by *Hemileia vastatrix* [33]. A number of intervarietal and interspecific crosses, involving *Coffea stenophylla*, *C. liberica*, *C. augenoides*, *C. arabica*, and *C. robusta* have shown hybrid vigour.

Until the early thirties, genetic improvement of tea was carried out in many estates through mass selection. Seedlings and clones of highly drought-resistant plants of the China type of tea collected from Uttar Pradesh proved useful in breeding work. Hybrid vigour, noticeable in some intervarietal crosses was also sought to be exploited. Certain characters like pubescence of the lower surface of the leaf, fragrance in the plant and in flowers appeared to be positively correlated with the quality of the tea. Further investigations include breeding for high yield, good brewing quality, and resistance to drought and to the 'grease spot' disease.

Narcotics

India ranks third in tobacco production in the world. Both *Nicotiana tabacum* and *N. rustica* are grown. In both these species, several improved types were bred by the Howards many years ago. The technique of flue-curing, first standardized here before 1933, greatly helped in expanding the cigarette-tobacco industry in this country. Breeding of types suitable for the manufacture of cigarettes, *bidi*, *hookah*, cheroots, and wrapper leaf has been undertaken and a good amount of genetical work has also been done [34]. Breeding for resistance to diseases such as mosaic, leaf curl, powdery mildew, *Fusarium* wilt, 'frog eye', leaf spot, and pests such as Orobanche, has also engaged attention, primarily at the Central Tobacco Research Institute, established at Rajahmundry in 1945.

Other narcotics, such as Indian hemp (*Cannabis sativa*) and poppy have so far not received much attention.

Spices and Condiments

India grows a variety of spices, which constitute an important export commodity. Considerable breeding and genetical work on chillies (*Capsicum annuum*) has been done at the Indian Agricultural Research Institute and in Madras and Bombay.

In other crops, such as cardamon, pepper, cinnamon, ginger, turmeric, coriander, fennel, and cumin, breeding work has been undertaken only recently, mainly through straight selection.

Recent Progress in the Science of Plant Breeding

Although the foundation of scientific plant breeding in India was laid some fifty years ago and undoubtedly valuable results were achieved before 1933, the last two decades and a half have marked a distinct progress in the science, practice, and organization of plant breeding in India. The Indian Council of Agricultural Research has played a significant role as the principal agency for the financing and co-ordination of researches in crop and animal husbandry and the commodity committees separately dealing with individual crops or groups of crops such as cotton, jute, sugar-cane, tobacco, oilseeds, and important spices and plantation crops have likewise done so in their respective fields. Besides the Indian Agricultural Research Institute, which is now the premier institution in the field of agricultural research and post-graduate training in India, separate central research institutes have been established for work on rice, potato, jute, tobacco, and coconut. The agricultural research institutes and experiment stations in the states throughout the country have expanded substantially. The food and agricultural problems of the country, and the expanding work of the organizations for agricultural extension, established after 1947, have helped in focusing attention on numerous problems, old as well as new, of local, regional, or national importance. The solution of these problems is now sought both through the fundamental as well as through applied researches. A central organization for plant introduction and exploration has been established at this Institute with the object of enriching the breeders' stocks through international exchange.

Plant physiological studies have been undertaken for an understanding of crop response to varying soil and temperature conditions, to drought, flooding, and conditions predisposing to lodging, with the object of gathering information which would assist the plant breeder. The possibility of commercial exploitation of heterosis is being increasingly explored. As has already been mentioned, work on distant hybridization has been undertaken to obtain knowledge of evolutionary origin of crop plants or for utilization in crop breeding. The scope of plant improvement through polyploidy breeding has been explored and a good measure of success achieved in crops such as Brassica and Egyptian clover [35]. Mutation research, utilizing X-rays, radioactive isotopes, neutrons, and other mutagenic agencies has been initiated and it has already produced some interesting and useful mutations in jute, sesame, cotton, wheat, and ornamental flowers. Plans are afoot to set up a

gamma field for mutation research at the Indian Agricultural Research Institute and one or two other centres in India. A unit for embryo-culture has been established recently at this Institute for tackling problems of cross-incompatibility arising from abortion of hybrid embryos and a certain amount of useful work has been done on the standardization of suitable media. Thus, endeavour is being made by the plant breeders in India to harness every useful modern method and technique with the object of making available to the farmers superior strains not only of food crops but also of the large number of other economic plants which are grown and utilized for the welfare of man.

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FIG. 1. A crop of Pusa wheat varieties N.P. 710 and N.P. 718

FIG. 2. Ears of wheat—N.P. 809. This variety has resistance to all the three rusts

FIG. 3. A stiff-strawed, non-lodging selection isolated by the Economic Botanist, West Bengal, from a cross between *indica* and *japonica* strains of rice

FIG. 4. Seedlings of diploid and tetraploid berseem of similar age, showing the increased vigour and tillering capacity of the tetraploid

FIG. 5. Variation in ear characters in X_2 plants of wheat strain N.P. 809 treated with radio-active phosphorus. The bearded mutant (1) is of economic interest. Various types of speltoids, compactoids, and branched earheads are also seen

FIG. 6. A plant of the long-staple cotton variety, Devitej (134 Co_2—M) derived at Surat from interspecific hybridization (*G. hirsutum* × *G. herbaceum*)

32. N
33. V

34. E
35. S

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ADVANCES IN OIL PALM RESEARCH IN NIGERIA IN THE LAST TWENTY-FIVE YEARS

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IN any paper dealing with oil palm research in Nigeria, mention must first be made of the peculiar environment under which the crop has become established and the trade in palm produce which has been developed. Trade in palm oil and kernels has been carried on in southern Nigeria for a very long time, and in spite of the establishment of plantations of oil palms on a large scale both in the Far East and the Belgian Congo, the semi-wild or 'domesticated' palms of Nigeria have continued to hold first place in the world's trade in both products.

The palm groves of eastern Nigeria and other parts of west and central Africa are unique in tropical crop husbandry. On the one hand they cannot be regarded as plantations, for the individual palms have rarely been planted, while on the other hand the oil and kernels cannot be regarded as forest products, for the shade of the primeval forest is too deep to allow oil palm seedlings to develop. The oil palm in West Africa has in fact followed man around in somewhat the same manner as a domestic or farm animal. It develops best near the homestead, but will also give a reasonable quantity of produce in farmland farther afield and in areas where homesteads have existed in the past [1].

It might well be thought that a plant which will look after itself and reproduce itself with little care or attention near human dwellings has necessarily found an environment under which it can produce a maximum of economic products. This, however, is not so. In the establishment of plantations in the Far East and in the Belgian Congo during recent decades it has been clearly shown that much higher yields can be obtained in these areas than have been obtained in countries in which the oil palm has established itself naturally. It is not safe to assume that a crop will grow best in the areas where it is found to be growing in largest quantity.

Though it has been thought for a long time that the establishment of plantations elsewhere might become a serious threat to the oil palm industry of West Africa, it was not until recently that much information became available on the yields of Nigeria's palm groves and the quality of the fruit available. Recent surveys have, however, confirmed the general impression that even the best palm groves give yields which are very much lower than those obtained from plantations in Nigeria, while the latter themselves give yields considerably lower than those obtained in the Far East. These surveys have also shown that the percentage of palm oil and kernels obtained from the fruit in natural palm groves is generally very low indeed [2].

It has been necessary therefore during the last 25 years to learn how to

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grow the oil palm as a plantation crop in Nigeria, to determine the difficulties and to overcome them. In the course of this work it has become apparent that some environmental factors in West Africa impede the easy establishment of plantations of oil palms and may prevent the production of the maximum quantity of bunches which the individual palm is capable of producing. These adverse environmental factors

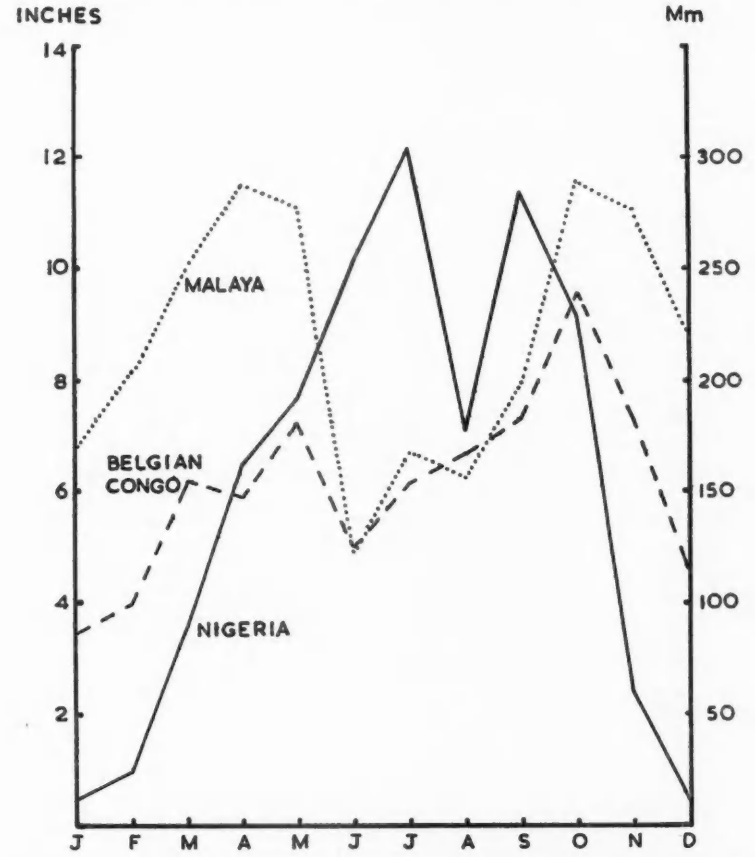

FIG. 1. Average monthly rainfall at centres in Nigeria (W.A.I.F.O.R. Main Station, Benin), Belgian Congo (Yangambi), and Malaya (Ipoh). The average annual rainfall at these centres is 72, 74, and 105 inches respectively, based on the periods 1940–56, 1929–55, and 1947–56 respectively.

are: (1) the long dry season lasting from November to the middle of March; (2) the smaller amount of sunshine in West Africa compared with other tropical countries; and (3) the deficiency of plant nutrients in the sandy soils on which the large areas of palm groves are found.

In the Far East oil palms are usually grown in an equatorial climate of much more even rainfall, average monthly sunshine rarely falls below 5 hours per day, while soils are usually of a higher nutrient status and

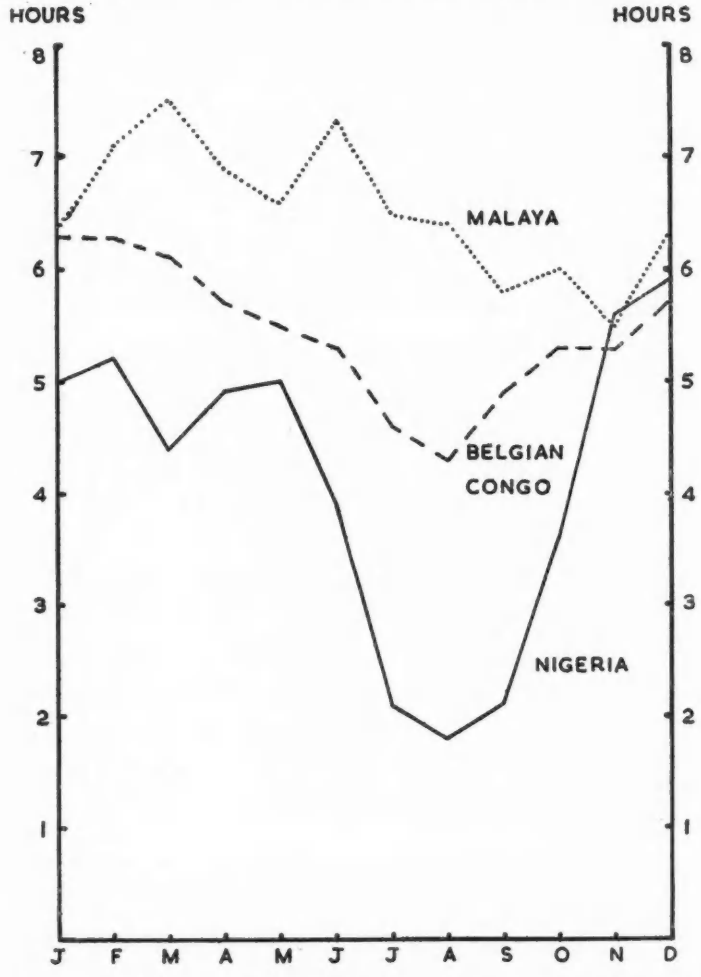

FIG. 2. Average daily sunshine in Nigeria (W.A.I.F.O.R. Main Station, Benin), Belgian Congo (Yangambi), and Malaya (Ipoh). The overall averages are 4·1, 5·4, and 6·50 hours respectively, based on the periods 1949–56, 1940–55, and 1950–6 respectively.

more retentive of moisture than those of Nigeria. The sharp contrasts between the climates of the oil palm areas of Nigeria, the Belgian Congo, and Malaya are shown in Figs. 1 and 2.

Research over the last 25 years has therefore been directed firstly towards the discovery of plant-production methods and planting techniques suited to the climate, secondly to the selection of parent palms with characteristics adapted to the climate, and thirdly to the maintenance and improvement of soil fertility. To this has been added a problem peculiar to the human environment in which the oil palm finds itself. Palm products are extracted by a community of farmers producing their own food and sometimes also food crops for sale [3]. It has been desirable therefore to investigate how far the two activities, food-crop farming and palm-produce production, can be combined.

Plant Production

Experiments mentioned later have shown that the planting of oil palms in Nigeria is best carried out before the wet season has fully set in. April and May plantings give the best results. While the direct planting of seed and the planting of very small seedlings has been tried with varying success, these practices have not yet found much favour, and the transplanting of seedlings about 2 to 3 feet in height and around one year old has been usual.

The need to produce suitably sized seedlings at a certain time of year has increased the difficulties of plant production and has made it necessary for a considerable effort to be put into research connected with germination and the raising of nursery seedlings.

Germination. In the Far East sunshine provides sufficient heat to give satisfactory germination of oil palm seeds in sand-beds. With the deficiency of sunshine in Nigeria, however, germination by such methods is slow and uncertain. A variety of artificially heated germinators [4] have therefore been evolved, but, in spite of this, germination has often continued to be erratic, and empirical trials dealing with such factors as temperature and media have seldom been conclusive. In 1954 a start was made in the laboratory with a much more fundamental study of germination problems. This study included investigations into the germination of embryos, kernels, and nuts and the effect on germination of varying temperature, oxygen concentration, and, in the case of nuts, moisture content [4, 5, 6]. It was found that with excised embryos there was no delay in germination such as is found with kernels or nuts, and that the germination of kernels could be much accelerated by germination in oxygen instead of in air. Further experiments with *tenera* kernels showed that the optimum temperature for germination was 40° C. Higher temperatures were lethal.

These experiments were carried out in conical flasks without media. When similar experiments with nuts were started, it at once became apparent that the determination and maintenance of an optimum moisture content of the whole nuts was of paramount importance. A series of experiments was started to determine the optimum moisture content for germination of both *tenera* and *dura* nuts. For *tenera* nuts this was found to be about 22 per cent. water on a dry-weight basis. Experiments in both air and oxygen were carried out, but the effect of increased oxygen concentration was not determined. With the thick-shelled *dura*

nuts the optimum moisture content for germination was found to be 17–19 per cent.

These experiments have thus determined both the optimum temperature and the optimum moisture content for the germination of both forms of oil palm seeds, and germination can now be carried out without medium in dishes covered with thin polythene sheeting.

The problem of seed storage remains to be investigated fully, though storage for up to 12 months in metal drums has been found reasonably satisfactory in recent years. Storage is necessary under Nigerian conditions owing to the fact that if 1-year-old seedlings are required for transplanting to the field in April and May, germination must be started each year between August and October. This means that seed has to be stored over a period of 1 year. It may be, however, that further research will make it possible to plant irrigated nurseries much later in the season and to force the seedlings forward for transplanting within 6 months. If this proves feasible it will then only be necessary to store seed for 6 months.

Raising nursery seedlings. One year has hitherto been considered the minimum necessary for raising a small seedling to transplantable size. The setting out of 'just germinated' nuts straight into the nursery has not proved very satisfactory, so the normal practice has been to establish these nuts in pre-nurseries which, in a permanent nursery area, have taken the form of raised concrete or wooden trays filled with top soil previously baked on a corrugated iron sheet [7]. The germinated seeds were spaced in these trays at 1½ in. and were considered ready for planting into the nursery when they had reached the three- or four-leaf stage. Later work has, however, shown that a good deal of improvement can be effected in the raised trays.

Early experiments showed that nursery planting was best carried out in April. Late-planted nurseries have always been unthrifty and have resulted in a low proportion of seedlings fit for transplanting in the following year. At Benin, where fresh forest sites have been available each year, organic manuring and dry-season mulching without cultivation were found to be of little value, but losses were reduced and the size and vigour of the seedlings were increased by watering at planting and in the dry season, and shading during the dry season [8].

Although these series of experiments led to some improvement in nursery practice, nurseries generally in West Africa remained very uneven and the percentage of one-year-old seedlings available for planting was often as low as 50–60. Moreover, in recent years the losses from Blast disease have increased. As a result of this unsatisfactory state of affairs a new and much more comprehensive attack on the problem of nursery cultivation was started during 1956 and expanded during 1957.

In the first place it was found that wider spacing of seedlings in the raised trays, coupled with mulching, gave rise to much more robust seedlings for planting into the nursery and a general change-over to wider spacing in the raised trays has taken place and it is now recommended. Secondly, a series of experiments was laid down throughout

Nigeria which took account of cultivation and manuring and the suitability of alternative sites for nursery establishment. It is as yet too early to draw definite conclusions from these experiments particularly as Blast incidence has been exceptionally low in the 1957–8 season, but there are distinct indications that recently opened nursery sites in which the forest soil has been left largely undisturbed are not favourable to nursery planting and that, on any sites, deep cultivation by ploughing or digging is advantageous. The best results have so far been obtained where such cultivation is combined with organic manuring or mulching with bunch refuse throughout the season.

The study and control of fungus diseases have formed an important part of investigations on nursery cultivation. Nursery seedlings are subject to a variety of diseases of which the most important are Anthracnose, Freckle, and Blast.

Anthracnose, described by Bull and Robertson [9, 10], has been shown to be of three different types, caused by the three fungi *Botryodiplodia palmarum*, *Melanconium* sp., and *Glomerella cingulata*. Anthracnose is the main cause of deaths in the nursery shortly after the seedlings have been transplanted from the raised trays, and it is largely responsible for the unevenness which is such a common feature of nurseries in the middle of the year. Those plants which recover from the disease are often unthrifty and may not survive the dry season.

Experiments have shown that Anthracnose can be largely controlled by spraying in the raised trays prior to transplanting and by spraying again at fortnightly intervals after planting. The most efficient fungicides tested are the organic fungicides, Thiram and Ziram. Perenox at low concentration has been found fairly successful but oil palm seedlings are unusually susceptible to copper toxicity and Perenox has therefore to be used with care. Furthermore, the practice of spacing seedlings more widely in the raised trays has assisted in the control of Anthracnose.

Freckle, caused by *Cercospora elaedis*, is also a leaf disease and it affects seedlings later in the season than does Anthracnose. The characteristics and control of the disease have been described by Robertson [11]. Spraying with organic fungicides has again been most successful and if severe attacks are encountered this spraying may be carried on for a year or two after transplanting into the field. If untreated the disease may cause a considerable retardation of growth in the nursery and it is yet another cause of the unevenness already mentioned. Moreover, a bad infection of the nursery will be carried over into the field and the seedlings will make poor growth during their first 3 or 4 years. The disease gradually disappears as the plants develop.

Blast disease has always been considered the most important of the diseases of the oil palm in the nursery and it is certainly the most lethal. In some nurseries as much as 50 per cent. of the seedlings have been lost. The disease, which appears to be confined to nurseries in Africa, is characterized by the destruction of the root cortex, and the effects of this destruction are spectacular. The leaves of the affected seedlings lose their glossy appearance and become flaccid, turning rapidly from green to olive-green or khaki. Within the course of a day or two all the

leaves die and dry up, while the central spear is found to have rotted at the base.

Years of study failed to reveal the pathogen of Blast, but more recently *Rhizoctonia lamellifera* and a *Pythium* sp. have been consistently isolated from roots showing primary infection [6]. There is little doubt that both *Rhizoctonia lamellifera* and *Pythium* sp. are concerned in the production of Blast symptoms and interesting studies of the inter-relationship of these two fungi have recently been carried out in the laboratory.

It seems most likely that Blast disease will eventually be eliminated from nurseries by a determination of the factors which hinder the growth of these two fungi. Careful studies are being made of soil moisture and temperature at the beginning of the Blast season while it has been noted that the more serious Blast years are those in which the total August and September rainfall is below average.

It should be noted that Blast is indiscriminate in its attack; both well-grown and poorly developed seedlings may succumb. Good cultivation of the nurseries will not therefore of itself cure the disease. It may, however, be possible to arrange nursery planting so that during the Blast season (October to January) seedlings are either at too old a stage or at too young a stage to be susceptible.

These considerations, among others, led to attempts to raise nursery seedlings during the off season, i.e. seedlings were planted at the end of the rains and attempts were made to force them forward by irrigation, cultivation, and manuring so that they might reach transplantable size by the following May. If this system proves successful it will have the added advantage of allowing seed to be set for germination twice yearly instead of only once a year.

Planting in the Field

It might be expected that the best horticultural practice in transplanting oil palm seedlings would be to dig them up from the nurseries with a good proportion of soil still adhering to the roots and to transfer them thus to the field protected by stout leaves, sacks, or some other material which would prevent the soil from falling away.

The problem of transplanting has not, however, appeared so simple in Nigeria. Although more large plantations having their own nurseries are now being established, the majority of seedlings are still required by peasant farmers who have to carry them many miles from central nurseries to the scene of planting. Early experiments on methods of transplanting were therefore largely concerned with time of transplanting and the method of digging up and transporting seedlings from nurseries to the planting site. These experiments [12] showed that three factors were essential: (1) to plant early, before the rainy season had fully set in; (2) to protect the planted palms against rodent attack with wire-netting collars; (3) to plant with a ball of earth. In spite of the fact that planting with a ball of earth would be quite unpractical for some of the peasant farmers requiring seedlings from central nurseries, experiments showed conclusively that with naked-root planting survival was always doubtful

and growth very poor. Two methods of overcoming these difficulties were then tried. These were root pruning of seedlings 4 to 6 weeks before planting, and the dipping of roots in a clay slurry before they were transported to the planting site. Although the plants treated in these ways were not quite as vigorous as those planted with a ball of earth, losses were negligible and both methods can be regarded as most suitable for the circumstances prevailing in Nigeria. It should be mentioned, however, that on plantations where planting with a ball of earth can easily be carried out, root pruning 4 weeks before planting has been found to be an additional improvement [5].

Selection and Breeding

As the oil palm is a monoecious perennial with no means of vegetative propagation, any programme of improving the production of the crop by selection and breeding is necessarily a long-term project. Any such project is further complicated by the very mixed genetic composition of the crop and by the fact that it gives two economic products which vary in their market value.

It has, of course, been known for a very long time that the African oil palm was to be found in three forms: the *dura* with a thick shell and comparatively low quantity of oil-bearing mesocarp; the *tenera* with a thin shell surrounded by a ring of fibres and with a comparatively large quantity of mesocarp; and the *pisifera* with no shell and with fruits which sometimes contain kernels but are sometimes abortive. Little real progress could be made in propagating high-yielding families of oil palms until the inheritance of these unusual characters had been explained by Beirnaert and Vanderweyen in 1941 [13]. Their studies showed that the crossing of the *dura* with the *pisifera* form gave rise only to *tenera* progeny while the selfing or crossing of *tenera* palms give rise to *dura*, *tenera*, and *pisifera* progenies in the proportions 1:2:1.

In view of the low proportion of shell contained by *tenera* nuts it was at once clear that the discovery of the means of producing large quantities of this form from the predominant *dura* palms of West Africa would be of the highest importance. The first *dura* × *pisifera* plantings in Nigeria were carried out at the Institute's Main Station in 1942 [14] while further plantings were made in 1945, 1946, and 1947. Although many of the early pollinations were unsatisfactory, nine different *dura* × *pisifera* crosses showed the expected segregation into 100 per cent. *tenera* and there was therefore no reason to doubt the correctness of the inheritance theory postulated by the workers in the Belgian Congo. The results of an earlier breeding programme carried out by Smith [15] confirmed the general inheritance theory. Of particular interest in the series of *dura* × *pisifera* plantings was the crossing of a Deli palm with *pisifera* pollen to give almost perfect segregation, on three occasions, into 100 per cent. Deli *tenera* progeny. The Deli palm, with which almost all the plantations in the Far East have been planted, is a *dura* in form but has certain distinct characters of which the most favourable are its high mesocarp content and large bunch size while the least favourable are its tendency to a low sex-ratio and high abortion rate [16]. It will readily be

seen therefore that a demonstration of the ability to produce *tenera* palms which might carry the favourable Deli characters was an important step forward.

Although a good deal of progress was made after the war in the production of improved seed for distribution, staffing difficulties made it impossible for our knowledge of fruit-form inheritance to be used to the full. While the number of palms of which records had been kept was small, the demand for seed in Nigeria was large. It is only in the last few years that parent palms at W.A.I.F.O.R.'s Main Station became old enough for use as seed producers. The old palms previously in use were at far-distant stations where supervision of pollination was necessarily infrequent. Both *dura* and *tenera* palms were selected as seed and pollen trees on the basis of yield and fruit characters, while *pisifera* palms had to be selected on appearance only. Bulk pollination has been employed, i.e. pollen from *dura* palms has been mixed and used for the pollination of *dura* or *tenera* palms, while bulked *tenera* pollen and bulked *pisifera* pollen have been used for pollinating *dura* palms. Recently *dura* × *dura* seed has ceased to be produced and all seed issued is now either *dura* × *tenera* (or the reciprocal) or *dura* × *pisifera* material.

The quality of the early seed produced at outstations has been discussed by Broekmans [17], but more recently he has developed methods of selection which take account of four main factors: (1) shell content to fruit, (2) percentage of fruit to bunch, (3) bunch yield over a period of up to 10 years, (4) height of palms. From these data three factors were obtained:

1. The proportion of mesocarp plus kernel to bunch: $C_1 = (1 - \text{shell/fruit}) \times \text{percentage fruit to bunch}$.
2. The total weight of mesocarp plus kernel over the first 10-year period: $C_2 = C_1 \times 10$ years bunch yield.
3. The yield of mesocarp plus kernel per unit of height: $C_3 = C_2/$ height of palm in feet.

The selection standards used for these factors have been as follows:

Tenera	*Dura*
Maximum shell content to fruit	
18 per cent.	38 per cent.
Minimum C_1	
50 per cent.	40 per cent.
Minimum C_2	
700 lb.	600 lb.
Minimum C_3	
40 lb.	35 lb.
Maximum height of the palm when 15 to 17 years old	
20 ft.	20 ft.

It will be noted that with these standards no special value has been given to the individual proportions of mesocarp and kernels. In fact, however, in the selection of mother trees, two kinds of *tenera* palms have been

emerging. Firstly there have been those (most favoured by plantations) with a high mesocarp percentage and small kernels, and secondly there have been those which, while maintaining a fair proportion of mesocarp, still produce a large-sized kernel.

Seed trials. The seed issued by W.A.I.F.O.R. for distribution to planters has been tested in trials planted at the Institute's Main Station. Yields obtained from selected and unselected planting material are shown in Table 1, while the results of bulk analyses from plots in one of the seed trials are shown in Table 2. Although in the *dura* × *tenera* and

TABLE 1. *Yields obtained from Selected and Unselected Planting Material in Recent Trials at Benin and Abak*

lb. fruit bunches per acre per annum

Trial	*Year planted*	*Yield period*	*dura* × *dura*	*dura* × *tenera*	*dura* × *pisifera*	*Selfed dura palm no.* 551.256	*Unselected*
Benin 32–6	1947	1951–6	4,257	4,739	4,571	4,523	3,107
		1956	7,034	7,854	7,335	8,327	5,229
Benin 32–7	1948	1952–6	4,095	5,776	5,010	4,739	3,882
		1956	6,817	6,983	6,317	7,145	5,548
Benin 32–9	1949	1953–6	4,241	4,931	4,874	4,765	3,923
		1956	6,249	7,385	6,951	6,598	5,917
Abak 506–1	1950	1954–6	4,782	3,773	4,263	4,109	3,167
		1956	7,102	5,688	6,724	6,568	4,601

TABLE 2. *Summarized Results of Twenty-two Bulk Analyses of Bunches from Seed Trial 32–6 at Benin from January to December 1956*

Bunches	*Fruit to bunch*	*Mesocarp to fruit*	*Kernel to fruit*	*Shell to fruit*	*'Loss'*	C_1*
	%	%	%	%	%	%
Dura bunches from progenies of selected palms	68·6	45·5	10·9	40·8	2·8	40·6
Tenera bunches from progenies of selected palms . . .	63·2	72·2	8·8	15·9	3·5	53·2
Dura bunches from progenies of 551.256 .	67·5	46·3	11·5	39·2	2·7	41·0
Dura bunches from unselected material .	65·5	42·4	12·6	41·4	2·9	38·4

* $C_1 = (1 - \text{shell/fruit}) \times \%$ fruit to bunch.

dura × *pisifera* crosses from outstations a higher proportion of *dura* palms has almost always appeared than would have been expected, nevertheless the results presented in these tables show the improvement in bunch yield and bunch analyses which have been obtained by the admittedly imperfect methods of the past. Further improvement will be effected by four means: firstly, by a full application of Broekmans's

standards; secondly by a wider selection within Nigeria including selections within Deli progenies; thirdly by the importation of progenies of good character from outside Nigeria; and fourthly by the gradual adoption of line breeding in place of the mass-selection method which has been used for seed production in the past.

Inheritance studies. During the last 10 years an attempt has been made to widen our knowledge of the inheritance of both form and type characters. Large numbers of progenies of *dura* × *pisifera* crosses have been planted and these are now coming into bearing; these programmes were designed to determine the effect of variations in the *dura* parent, and to assess the value of a wide range of *pisifera* parents.

More recently a study by Purvis [18] has shown that different colour values are obtained from two different types of fruit, the colour value of one type being about four times greater than that of the other. The inheritance of these characters is now being studied.

Studies of growth and flowering. In the fields at the Institute's stations where progeny trials or breeding material have been planted, detailed and regular observations on the growth and flowering of the palms have been made for many years. Some of these data were recently studied by Broekmans [16] and it is likely that the deductions drawn from this study will be of considerable value in future breeding work. Briefly Broekmans showed the profound importance of the sex-ratio in determining yield of palms in West Africa and he indicated how the climatic factors peculiar to Nigeria influence not only the stage of sex differentiation but also the development of the female inflorescence. Variations in annual bunch yield were shown to be due to variations in leaf production, sex-ratio, floral abortion, and weight per bunch. Floral abortion is likely to have an important influence only in young palms, and fluctuations in bunch yields in mature areas are therefore very largely under the influence of variation in sex-ratio. It is clear therefore that both the selection of palms with a naturally high sex-ratio and the discovery of cultural and manurial treatments which encourage a high sex-ratio should take an important place in oil palm research in the future.

Maintenance and Improvement of Soil Fertility

Very little attempt was made in the pre-war period to improve soil fertility or to increase the out-turn of oil palm products by means of fertilizer applications. In those early days the attention of the Department of Agriculture was largely concentrated on the maintenance of fertility by applications of organic material such as farmyard manure or cover crops. Applications of lime were also tried. These experiments did not yield any very striking or economic results although some small responses to farmyard manure were noted in certain areas and have been described by May [19].

It was not until applications of wood ash in an experiment on a very degraded soil at Nkwele in Onitsha Province had shown spectacular results in the early 1940's that the way was open for the use of fertilizers and for a much more scientific appreciation of the oil palm's needs. Hale [20] made spectographic analyses of leaves of palms suffering from

the condition known as Confluent Orange Spotting and was able to show that potassium was likely to be the primary deficiency of these infertile areas. The success of the wood-ash application had also, of course, suggested a potassium deficiency, and a subsequent experiment in the same area, using potassium sulphate, confirmed the importance of this element. Thereafter, responses to potassium appeared in other trials in the Eastern Region of Nigeria and it became obvious that it would be difficult to find an area where potassium was not required. In most areas Confluent Orange Spotting was to be found in all planted plots and in many palm groves as well. Although it is not yet certain that this is a primary symptom of potash deficiency, the application of potassium has everywhere been shown to reduce its incidence.

Perhaps the most interesting example of the extent to which potassium deficiency can reduce yields is shown by an experiment at Umudike in the centre of the Eastern Region. In this area a single application of potassium chloride at the rate of 5 cwt. per acre almost doubled the yield from 30-year-old palms in the second year after application and the plots receiving that initial dressing have maintained their yields and their ascendancy over the controls for a further 6 years [21]. The effects of the single potassium application in this remarkable trial are shown in Fig. 3.

The realization of the poverty of West African soils in mineral nutrients and the recognition of some of the different deficiency symptoms in oil palms has led naturally to fertilizer and other agronomy experiments being supplemented by investigations into deficiency symptoms and by studies of the soil.

Studies of leaf chloroses. For many years it has been recognized that in Nigeria there are two main types of 'leaf yellowing' and that a condition now known as Orange Frond disease, though not as widespread as Confluent Orange Spotting, was nevertheless to be found quite commonly in the south-eastern provinces of Nigeria. In 1952 and 1953 Bull [22] conducted injection experiments which showed that Orange Frond disease responded very rapidly to leaf injections of magnesium. His experiments, which have been described in considerable detail, were followed immediately by a fertilizer experiment in the area near Calabar where the injection trials had taken place. It was shown that, within 18 months, soil applications of magnesium sulphate at the rate of 5 lb. per palm (2½ cwt. per acre) reduced the incidence of Orange Frond disease to a remarkable degree. Responses in yield followed, and by 1955, 2 years after the first applications, increases in bunch yield of the order of 50 per cent. had been obtained and the percentage of bearing palms had been substantially increased [23].

It has been shown therefore that not only can Confluent Orange Spotting and Orange Frond disease be substantially reduced by soil applications of the appropriate nutrient, but greatly increased bunch yields will also follow.

Confluent Orange Spotting and Orange Frond are by no means the only nutrient deficiency symptoms to be found on the oil palm in West Africa. A number of other conditions have been detected and described

and sand-culture work has been started with the object of determining the causes of these symptoms. At the same time leaf analyses are being undertaken with material from areas showing the various symptoms.

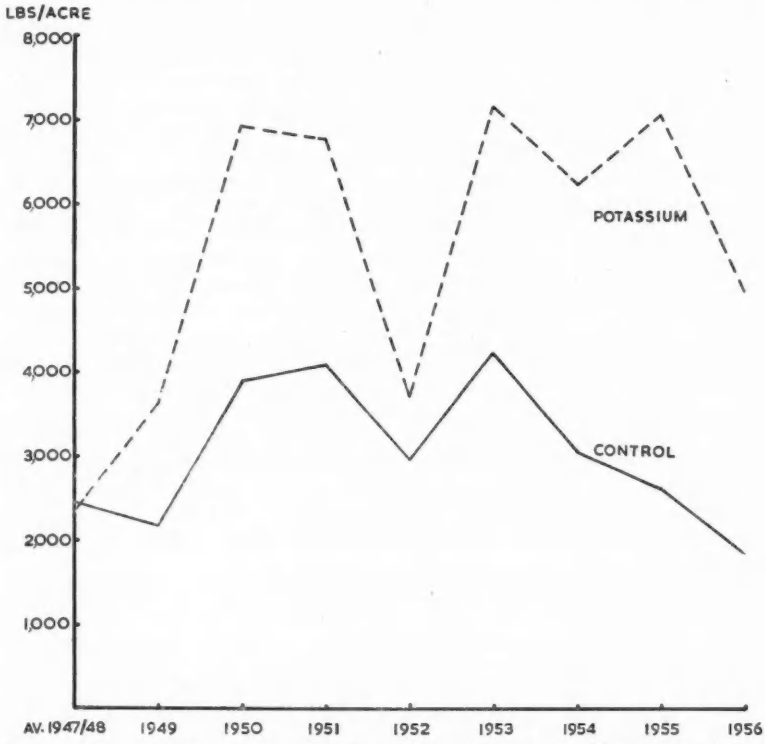

FIG. 3. The effect of a single application (in November 1948) of 5 cwt. of potassium chloride per acre on the yield of fruit bunches over a period of 8 years. (Umudike, Owerri Province, Eastern Nigeria).

Soils studies. A considerable amount of data relating to the soils in the palm belt of Nigeria has been collected and published by Vine [24]. The general conclusion from his studies of soil profiles at the sites of oil palm experiments has been that there is a fundamental similarity throughout the soils. These have been formed from materials containing only very small amounts of plant nutrients and have been subjected to intense and prolonged leaching. Analyses showed that this leaching was more intense, and that the soils were more acid, in areas with over 80 to 90 inches of rainfall per annum. These areas are to be found largely in Owerri, Rivers, Calabar, and part of Onitsha Provinces, while in Benin Province, where the rainfall is rather less, the soils are less acid and leaching less intense. It has, of course, been recognized that the degradation of soils is not merely a matter of rainfall and other climatic

factors. Intensive usage of the land for annual crop farming is of enormous importance since the supply of nutrients is largely the result, as Vine points out, of accumulation by plants in a cycle of growth, decay, and reabsorption. Thus some of the most impoverished oil palm plots in Nigeria, including the plot where the need for potassium was first detected, lie in areas with an annual rainfall of only 70 inches.

Determinations of exchangeable potassium vary largely in Vine's published data. The significant fact is that the amounts of exchangeable K were found to be very low almost everywhere, even by comparison with other tropical soils.

Very recent work at the Institute [6] has aimed at investigating the relationship between nutrient deficiencies, as shown by yield responses and visual symptoms, and routine soil analyses. The work is of such recent date that little detail can be given here since there has not yet been time for a proper assessment of all results. A very marked relationship has, however, been shown between exchangeable magnesium in fertilizer experimental plots and the Orange Frond leaf sympton referred to above. The limiting level of exchangeable magnesium at which deficiency symptoms may be expected has been tentatively set at about 0·15 m. eq./100 g. (18 p.p.m.). No clear relationship has been found between exchangeable potassium and either the Confluent Orange Spotting symptom or the yield response to potassium fertilizers, but a relationship has been found with the mole fraction of exchangeable potassium in the top soil. Critical levels have not yet been determined but areas with a mole fraction of less than 0·01 are thought to be definitely deficient.

An interesting feature of the studies of the potassium requirements of the oil palm has been the relationship found between the supply of this element and the incidence of Vascular Wilt disease caused by *Fusarium oxysporum*. The disease was first diagnosed by Wardlaw [25, 26] in the Belgian Congo, and was later confirmed by him in Nigeria where it has been confined to three estates [27, 28]. Recent work by Prendergast [29] has shown that application of potassium fertilizers reduces the incidence of the disease significantly.

The work on the deficiencies of potassium and magnesium in Nigeria over the last 10 years has been outstanding and, if made use of, should lead to a considerable improvement in oil palm yields.

Planting Oil Palms and Farming

In a country where perennial crops are planted by peasant farmers there is always a desire to make use of the land during the more or less lengthy period before the crop comes into bearing. The effect of intercropping on the subsequent yield of an oil palm plantation has been studied in several experiments in Nigeria and an account of these has been given in some detail by Sparnaaij [30]. These experiments were carried out on the relatively fertile forest soil of Benin Province and on two impoverished soils in eastern Nigeria.

It has been shown that intercropping everywhere stimulates the growth of the oil palm in the early years, but that where soil fertility is low, the

favourable effects on yield soon disappear and may rapidly become negative. There is therefore a clear indication that, if intercropping is to be carried out during the period between planting and bearing, manuring of the palms will be required.

In Nigeria, however, the question is not only one of whether and how annual crops can be grown in a young plantation. The manner in which oil palms are grown in Nigeria was briefly described at the beginning of this article. The cultivator of oil palms and of food crops is one and the same person and whether he should grow these crops together or apart is a question of considerable importance throughout the country. In certain parts of Nigeria the palm oil producer might wish to be a grazier as well.

A large experiment on the intercropping and intergrazing of wide-spaced oil palms was started in 1945 [6] and it has been established that elephant grass grows well between wide avenues of palms and can be satisfactorily grazed. The problem of intercropping was not, however, satisfactorily dealt with in this experiment owing to the fact that some of the oil palm spacings used have subsequently proved unsuitable. The markedly increased yields obtained in Nigeria from palms on the edge of a field has suggested that twin-row spacing with wide avenues left for cultivation between the pairs of rows might not only provide areas for rotational farming but would also increase the yield of the individual palm so that the total yield per acre might be very little diminished. Experiments on these lines have recently been laid down both in relatively fertile and in impoverished areas in Nigeria.

Acknowledgement. The author is grateful to members of the research staff at W.A.I.F.O.R. for assistance and criticism in the preparation of this paper.

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PASTURE RESEARCH AND DEVELOPMENT IN NEW ZEALAND, 1933–57

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THE foundation year of the *Empire Journal of Experimental Agriculture*, 1933, saw New Zealand in the midst of an extremely serious economic depression which was felt particularly severely by its farming community.

Deterioration was abundantly evident over large areas on which poor pastures had been established following the burning of forest and scrub, and which pioneer settlers knew not how to maintain. Weedy pastures and stock illthrift appeared to be extending. The search for good grasses and clovers which would persist on soils of decreasing fertility was proving futile. Arable lands were becoming cropped out and no means for restoring their fertility was evident.

However, the foundations for a better future were being laid. The practice of top-dressing pastures, inaugurated in the Waikato, was showing promise on certain classes of land, though the action of the fertilizer was very imperfectly understood. In 1928 systematic pasture and fertilizer trials were commenced on the Marton Experimental Farm of the Department of Agriculture, while the following year saw the establishment of the Plant Research Station at Palmerston North, with the help of a grant from the Empire Marketing Board. A. H. Cockayne, who with E. B. Levy had for many years been carrying out field investigations on the ecology of grasslands, was appointed Director of the Plant Research Station. The years 1928–9 may be regarded as the foundation years of New Zealand's grasslands research.

By 1933 the first-fruits of this establishment were in evidence. A. W. Hudson, as Crop Experimentalist of the Department of Agriculture, had published a bulletin dealing with many of the problems arising from top-dressing of pastures, based on experiments conducted at Marton. The first certified seed of a few pasture species, which had shown superior qualities in the testing grounds of the Plant Research Station, was available to farmers. William Davies had shown the importance of strain in pasture species by selecting locally white clover strains of outstanding quality.

The future progress of grassland research may be said to have stemmed from two original sources, plant ecology and top-dressing, which gave the first gleams of hope to a farming community which in the 1930's was facing a very difficult situation. The year 1931 saw the formation of the New Zealand Grassland Association, a body which early recognized the importance of grasslands in the national economy, and which has, over the years, stimulated research and interest in every phase of pasture study. In 1935–6 the Plant Research Station became

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the Grasslands Division of the Department of Scientific and Industrial Research, entirely devoted to pasture research.

From the outset the experimental techniques and analytical methods devised by R. A. Fisher, 'Student', and Yates were used critically and adapted to the particular needs of the trials. The advances made by Stapledon and Davies in the fields of plant selection and breeding, by Martin-Jones in pasture management, and by Woodman in pasture chemistry, at this time were freely drawn upon. Hence, the soundness of the new knowledge gained inspired all-round confidence, so that farmers were prepared to accept and to put into practice the findings of grassland research workers.

Selection and Breeding

In 1933 at the Grasslands Division, following the work of William Davies, pasture plants comprising a wide range of grasses and clovers had been assembled from all parts of New Zealand for examination, testing, and recording, both as single plants and in swards, under mowing and grazing management. Plants raised from seed imported from overseas were grown under similar conditions for comparison.

The purpose of this work was to find strains of each species which showed characters superior to those commonly found in existing New Zealand swards. Field observations had shown the ryegrasses and white clover to possess, in greater degree than other grasses, properties suitable for New Zealand pastoral conditions. Concentration of effort was consequently devoted to these two species. Widespread complaints from farmers asserted that ryegrass failed to persist, and its place in swards was taken by weedy grasses. White clover too disappeared very readily from pastures in many areas. Persistency therefore was a quality in strong demand. The longevity of perennial rye-grass from Hawkes Bay excelled that from Canterbury and Southland, where 'false' perennial ecotypes had emerged, because their prolific early growth and seed production suited a type of farming where seed was of greater importance than pasture, pasture being regularly ploughed up for cereal and root crops. Within the Hawkes Bay collection, variation in longevity appeared, and selection, which involved also a search for other desirable agronomic characters, such as habit and season of growth, yield of dry matter, palatability and freedom from rust, sorted out the best strains for propagation. The seed of high-quality perennial ryegrass strains was then transferred for multiplication and certification under the Certified Seed System of the New Zealand Department of Agriculture. It was found that occasional fields of ryegrass in Hawkes Bay and elsewhere contained swards of pure high-grade perennial ryegrass which qualified for certification. The ultra-violet light test proved very useful in revealing the false-perennial content of samples of perennial ryegrass seed, and hence enabled a speedier build-up of supplies of 'Mother' Hawkes Bay perennial ryegrass seed through the certification system. The success attending the discovery locally of outstanding strains of perennial ryegrass was not repeated with Italian ryegrass, the best strains of which were found among imported lines.

Hilgendorf and Calder at Lincoln College had turned their attention to another ecotype grass, Akaroa Cocksfoot, and, following up selection of local strains, evolved by hydridization, an improved type possessed of a finer leaf and denser sward than its parents. This was known as C.23, certified, and issued for multiplication in 1938. Recently Corkill at the Grasslands Division working on the Akaroa and C.23 strains of cocksfoot, seeking a strain possessed of greater seedling vigour, better seasonal spread of production, and greater rapidity of recovery after grazing, evolved, after exhaustive trials, one particular strain which showed at Palmerston North, Lincoln, and Gore, particularly in spring, increased production at all seasons of the year. This strain now replaces C.23 in the certification system as Pedigree New Zealand Cocksfoot.

Corkill, seeking to improve the Hawkes Bay perennial ryegrass, produced at Grasslands a pedigree strain which showed some improvement, but criticism of these perennials, on the score principally of their unpalatability to stock, led him to embark in 1937 on a prolonged breeding and testing programme of hybridization between strains of perennial ryegrass and of Italian ryegrass, the aim being a ryegrass possessed of the best qualities of both species, which would suit New Zealand farming by providing the early spring growth, the palatability, and the freedom from rust, characteristic of Italian, with the persistency and summer production of perennial. There was an excellent range of material available at Grasslands for this purpose. After experience with four methods of breeding, he decided to use the polycross method. The pedigree strains resulting from hybridization undergo a series of tests involving chemical analysis, mowing and grazing trials, &c., at Grasslands. Those which show most promise are tried out further in different climatic and soil habitats throughout New Zealand and their performance evaluated by officers of the Department of Agriculture. Finally a selection is made and the approved new strain accepted for certification.

From his hybridization of perennial ryegrass (*Lolium perenne*) and Italian ryegrass (*Lolium multiflorum*) Corkill produced H.1 (Hybrid No. 1) or short-rotation ryegrass which entered the Certification system in 1942. The new hybrid was well received, particularly on account of its high initial first-year production and its increased yield, as compared with perennial, during the winter months. Measured results of first-year yields of three ryegrasses, in dry matter per acre, were: short rotation 9,352 lb., Italian 7,590 lb., perennial 7,430 lb.

As farm experience with this new strain grew, so were a number of its other advantages revealed, and Corkill continuing his investigations has produced every few years a 'new model' short-rotation ryegrass, differing somewhat from its predecessors largely because of the different amounts of perennial and Italian 'blood' in its pedigree. Improvements in persistency, for example, show a trend towards the perennial side as shown in this table:

Original short-rotation	39% survival
1945 strain	46% "
1956 strain	81% "
Certified perennial	97% "

In farm practice, especially under lenient summer grazing, short-rotation has in trials persisted for 4 years to comprise 50 per cent., and the largest single component of a mixed sward.

Short-rotation ryegrass has been the outstanding new development in pasture plant breeding and has indicated that the genus Lolium possesses, in addition to its capacity to produce a higher yield of dry matter annually than other grasses, pliability in the hands of the plant breeder to be made adaptable to farm requirements. This point is revealed in the following table showing the seasonal production of four types of ryegrass, and the changes which Corkill has been able to bring about in his short-rotation strain.

Strain	*Winter*	*Spring*	*Summer*	*Autumn*	*Total*
Perennial ryegrass . .	100	100	100	100	100
Latest short-rotation ryegrass	168	101	81	102	107
Original short-rotation ryegrass	174	89	52	30	82
Italian ryegrass . . .	167	91	48	18	79

The work on white clover, inaugurated by William Davies, has been followed up when field tests for improved yield and quality were shown to have a high correlation with the HCN content of the foliage. This test has been used in the production of strains which possess vigour, leafiness, and persistence of a very high order. White clover has shown, in the hands of the plant breeder, a versatility similar to ryegrass. After studies of its genetical composition, Corkill has produced strains which have very high and very low HCN contents both associated with excellent agronomic characters. New Zealand pedigree No. 1 white clover possesses a remarkably vigorous growth quality and persistence in marked contrast to the 'volunteer', puny, short-lived types which formerly prevailed.

As a result of the selection and breeding work done by Corkill and his associates, pedigree seeds of perennial, Italian, and short-rotation ryegrasses, cocksfoot, timothy, and of white, red, Montgomery, and broad red clovers are now available. With the progress of years, a profound influence is being exerted upon the pastures of New Zealand by the infusion of this new blood.

Seed Certification

Seed certification, inaugurated by J. W. Hadfield and continued by his successor J. H. Claridge, was first applied to the seed of pasture plants true to type in 1932. At first it was received with misgivings but with the passage of years under high-integrity administration by the Department of Agriculture, it has exerted profound beneficial effects, and has acquired a full measure of confidence from farmers and the seed trade. It must be emphasized that without certification the work of the plant breeder would be a waste of time and his efforts would bear little permanent fruit. Year by year, fresh nucleus seeds from the plots of the Grasslands Division, tested by the Seed Testing Station of the Depart-

ment of Agriculture, are fed into the Certification system, and so the standard and quality of the different grades of certified seed are maintained. The inevitable deterioration which occurs through contamination, unless this regular infusion of the highest-quality seed takes place, is therefore avoided. The Certification system has five quality grades of seed:

1. Nucleus stock—produced regularly under Grasslands Division supervision.
2. Government stock—produced on special areas under supervision of the Department of Agriculture.
3. Pedigree stock—produced by farmers who have obtained Government stock seed from merchants to whom it was released by the Department of Agriculture.
4. Mother seed—produced by farmers from pedigree seed certified in the field by the Department of Agriculture.
5. Permanent pasture—produced by farmers and certified by the Department of Agriculture.

Over the years, pasture-seed certification has shown steady expansion, a considerable proportion of the total pasture seeds produced annually being certified.

Pasture Management

It was probably the successes and failures attending top-dressing with phosphate and lime which touched off the interest which ultimately came to recognize pasture as a crop. The extensive field experiments conducted at Marton by A. W. Hudson and reported in D.S.I.R. Bulletin No. 31, *Investigations into Pasture Production*, dealt with many of the questions concerning pasture responses to top-dressing which were prominent at the beginning of the period. In the absence of sound knowledge of the varied soil types, of the facts of pasture management and the reaction of stock to pasture, extensive field investigations seeking factual information on the reaction of pasture species to top-dressing, mowing, and grazing were essential preliminaries.

One of the obvious beneficial results of phosphate application was the consequent growth of clovers which provided a better balance of feed and hence a sward more palatable and attractive to stock. However, many cases occurred where phosphate top-dressing gave little or no return, and only slowly was it realized that pastures devoid of clovers, as indeed was then often the case, would not respond to treatment. Again, because the need for judicious stock-grazing management was not appreciated, excessive growth of clover often proved a mixed blessing.

The success attending the use of phosphatic fertilizers, and particularly superphosphate, was such as to encourage the hope that pasture grazed *in situ* would provide adequately for milk-producing animals, dairy cows, beef cattle, and sheep all the year round, without there being need to grow supplementary fodder crops, though pasture hay or ensilage would be required. Hence assessments of the needs of stock and the production of pasture during all seasons of the year were made and used

as guides and demonstrations as to where pasture studies were required to deal with deficiencies and surpluses. An example of such assessment made by C. P. McMeekan is given in the two following figures (Figs. 1 and 2).

The objective of complete reliance on pastures for the needs of cattle

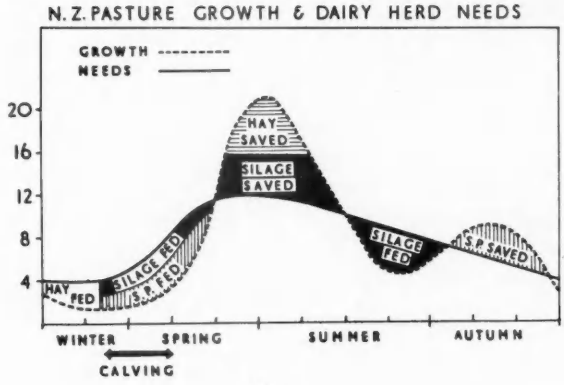

FIG. 1

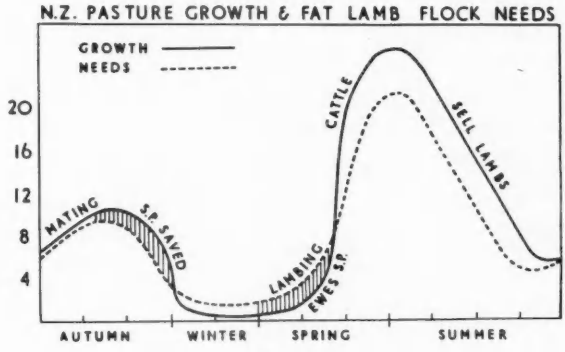

FIG. 2

or sheep directed more particular attention to the quality of the herbage. Woodman's results revealing the high nitrogen content and high digestible-protein composition of grass in its younger stages of growth were confirmed by Hudson and Doak, and field experiments were designed to test by mowing and grazing techniques what maximum production of dry matter of highly digestible protein per acre could be obtained by different systems of pasture management. The result of these indicated that swards of 3–6 inches growth provided consistently high percentages (15–20 per cent.) digestible protein, but those which were allowed to grow to a greater height (6–9 in.) produced annually the greatest quantity of digestible protein. This threw light on the variable

experiences of farmers in the results attending their use of fertilizers, and drew attention to the need for studies of pasture management by stock grazing in order to secure best returns. Close, controlled, and rotational grazing methods as practical applications of these findings were recommended to farmers who welcomed the increased production of protein these practices made possible.

At a later date Sears and Goodall's investigations showed that New Zealand pastures compared more than favourably with those of the United Kingdom as regards both crude-protein content, and digestibility of organic matter as reported by H. E. Woodman.

	New Zealand	*United Kingdom*
Digestibility of organic matter . . .	85·7%	79·6%
„ „ crude protein . . .	85·3%	76·3%

New Zealand pastures 8–10 in. in height were shown to have higher digestibility than those cut weekly or fortnightly in Woodman's trials. High digestibility (85·7 per cent.) remained characteristic of New Zealand pastures when they had reached heights of 10–14 in. in 6–7 weeks' growth, but immediately after flowering a rapid fall in digestibility occurred.

The question of how frequently a pasture could be grazed to give best results was the subject of much investigation and the results of one trial at Marton may be quoted.

Four plots of an old mixed pasture were cut at weekly, 2-weekly, 3-weekly, and 6-weekly intervals respectively for 4 consecutive years with the following dry-matter yields in lb. per acre.

	Plot 1 cut weekly	*Plot 2 2-weekly*	*Plot 3 3-weekly*	*Plot 4 6-weekly*
First year	2,954	4,266	5,020	6,754
Second year	3,374	4,265	4,907	6,637
Third year.	2,390	3,750	4,860	6,460
Fourth year	3,860	4,570	5,250	6,610
	12,578	16,851	20,037	26,461

In practice, the advantages of rotational grazing by a method in which the sward is harvested rapidly, through crowding stock on to it (mob-stocking) so that it is consumed in 1 or 2 days, and then allowed a fortnight or 3 weeks to recover, are now widely recognized. This represents an endeavour to attain maximum utilization of all the nutritive material produced in a sward, which is the aim of efficient management. The conversion of pasture to food products has been shown to be improved markedly by close subdivision so that stock grazing can be better controlled. Annual butterfat production of over 300 lb. per acre and meat yields of over 250 lb. per acre are now regularly attained by stock grazing entirely on grass.

A characteristic common to both indigenous and old, poor, sown pastures was their low clover content. Lack of response to phosphate

top-dressing drew attention to this factor. The significance of a proper balance between the clover and grass composition of a pasture sward became evident and the function of the clover was closely studied. Its response to phosphate stimulus resulting in greater absorption of atmospheric nitrogen through its root rhizobia, provided supplies of the very expensive plant nutrient, nitrogen. It had long been recognized that grass growth was limited by lack of available soil nitrogen, but it was only vaguely realized the extent to which this could be supplied by clovers. At Marton, Hudson had carried out trials in which pastures were top-dressed with ammonium sulphate, which certainly stimulated spring and autumn growth, which was somewhat unpalatable and was succeeded by a 'slump' in which a harsh sward appeared. At this time, nondescript white clovers prevailed, whose capacity as nitrogen collectors was poor by comparison with certified types produced by Corkill. In a trial at Grasslands, a pedigree white clover absorbed 460 lb. atmospheric nitrogen per acre compared with 260 lb. by a nondescript type. Under the mild climatic conditions enjoyed by New Zealand, the fixation of atmospheric nitrogen annually by clovers is large, and Sears (1953) in trials at Palmerston North showed a nitrogen increase of 550 lb. per acre which could be attributed to clovers.

In a similar series of field trials at Palmerston North, Sears showed the influences exerted on pasture yields and composition by fertilizers, the grazing animal, and the seed mixture. This is set out in Fig. 3.

A prominent objective of grassland research in New Zealand has been the provision of adequate feed for the grazing animal entirely from grass during each season of the year. This involves judicious attention being given to breeding, top-dressing, and management of pastures. The extent to which such can be achieved can be seen from the following table which shows the seasonal requirements of a dairy cow calving on 1 August and producing 400 lb. of butterfat in 300 days, compared with the yields of dry matter from a well-managed pasture.

	Percentage of pasture yields	*Percentage of feed required*
Spring	40	38
Summer . . .	27	30
Autumn . . .	23	19
Winter	10	13

The New Zealand policy aimed at high-producing swards has been to reduce the number of species used. This has meant a reduction to ryegrass/white-clover-dominant pastures, a mixture which has shown its worth where climatic conditions in summer and autumn are not unduly severe. This simplification has brought forth objections on the grounds that such pastures, no matter how high their total production of dry matter, are unattractive and unsuited to the diet of grazing animals. This certainly was the case with both mother and pedigree perennial ryegrass, which in spring months provided a most attractive-looking

forage, yet was shunned by stock for considerable periods. Pedigree short-rotation ryegrass, in marked contrast, with its content of Italian ryegrass 'blood', came as a welcome improvement, for it possessed an almost constant high palatability.

Before the breeding programme proceeded very far, and in view of

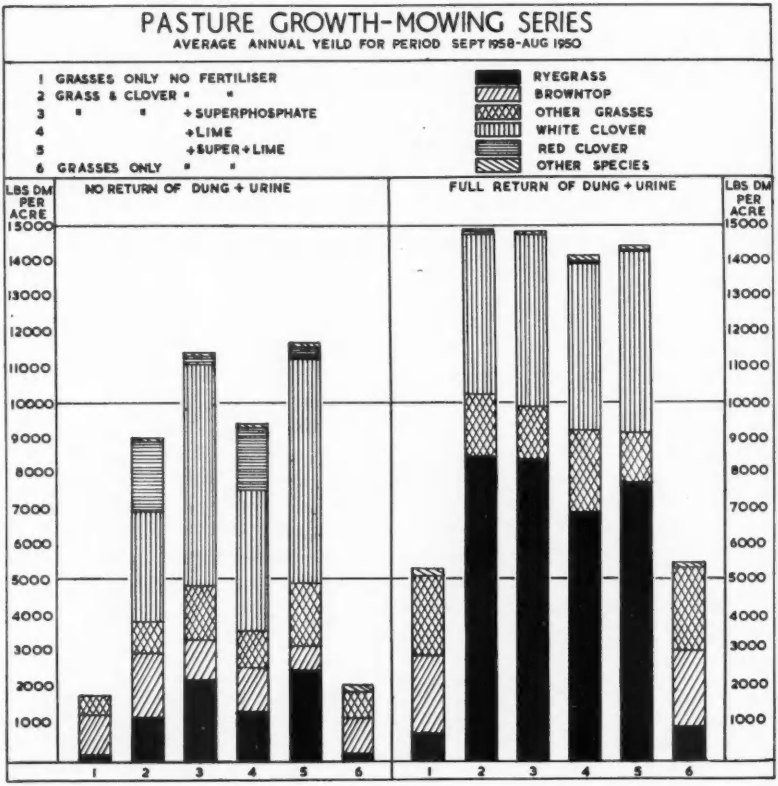

FIG. 3

farmer criticism, it was decided to conduct a comprehensive field scale trial at Massey College to ascertain the reaction of sheep and cattle to the newer selections and pedigree strains of pasture plants. These trials ran for several seasons and showed that, properly managed, pedigree pasture provided forage which suited the grazing animals, as was revealed by liveweight gains, wool and mutton production, lambing percentages, and morbidity, &c. The importance of a proper balance between clover and grass in the sward was plainly shown in this trial. The results were very encouraging to the policy of plant breeding, indicating also that the methods adopted for the testing of all new

strains and species were appropriate to the ultimate use to which they would be put.

Nevertheless, chemical analysis has always been resorted to as a guide in all research dealing with breeding and management of pastures. The simple ryegrass/white-clover pasture in New Zealand gives a ryegrass dominance in winter and spring, followed by a clover dominance in summer and autumn. In trials, marked fluctuations have been shown in the protein content of the grass component of a sward, being high in late autumn, winter, and spring, and low in summer and early autumn. A good balance between the grass and clover contents of the sward in trials has shown the possibility of reducing these fluctuations to a minimum. Improved pastures, fully stocked, have a high protein content during the winter in New Zealand, and this accounts for the fact that for the most part, stock are maintained throughout the year entirely on a pasture diet, an objective which was the aim of grassland scientists when they first recognized what high yields of rich-protein material could be obtained by due attention to pasture strains, appropriate phosphate fertilizers, and proper stock grazing.

In a country in which the animal depends for its sustenance to such a large extent, indeed almost entirely, on pasture consumed *in situ*, it was obvious that studies of the influence of stock on the sward itself would be necessary. Sears and Newbold at Grasslands (1942), using specially designed harness for the collection of dung and urine from sheep, studied the influence of the return of animal excrements on the composition and yield of the pasture. This is shown in the following table.

Treatment	*Pasture yields*	*Resulting nature of sward*
No return . . .	11,000 lb. dry matter	clover dominant
Dung returned . .	12,300 lb. ,, ,,	clover dominant
Urine returned . .	12,600 lb. ,, ,,	ryegrass dominant
Urine and dung returned	13,700 lb ,, ,,	well-balanced ryegrass, clover pasture

The full-return area received a minimum of 300 lb. of nitrogen per acre, the equivalent of a dressing of some 1,400 lb. of ammonium sulphate, in a form which was soluble and readily available. Where pastures capable of producing 12,000 to 14,000 lb. dry matter per acre annually are fully grazed, the stock excrements have been shown to possess a value of some £20–£30 per acre.

The efficiency of dry sheep in utilizing the nutrients provided by a pasture producing 14,000 lb. dry matter annually was also assessed by Sears on the basis of 4 years of field trials, and is shown in the following table:

	Content per acre of a 14,000 D.M. pasture per year	*Measured return from grazing dry sheep*
N equiv.	27·9 cwt. ammonium sulphate	20·5 cwt. ammonium sulphate
CaO ,,	2·4 ,, calcium carbonate	2·2 ,, calcium carbonate
K_2O ,,	17·1 ,, 30% potash salts	13·8 ,, 30% potash salts
P_2O_5 ,,	6·5 ,, superphosphate	5·7 ,, superphosphate

These results indicate the extent to which under a system of rotational grazing and rapid pasture growth, plant nutrients derived from mineral fertilizers may be absorbed from the soil by the plants, digested by stock and voided, to be again absorbed by grasses and clovers and so kept in circulation, avoiding fixation by the soil.

The economic advantage arising from the fact that New Zealand's climate permits 10 per cent. of its annual pasture production to occur during the three winter months is significant.

As a result of due attention being given to the nature of the soil, to appropriate top-dressing, to proper balance of clovers and grasses of known pedigree, and to sound grazing practices, many good pastures are at present producing from 10,000 to 15,000 lb. dry matter per acre with a seasonal spread comparable to that shown in the following table, which gives details of measured yields at nine widely separated locations in New Zealand.

Pasture Production in New Zealand (*'Journal of Agriculture', July 1956, P. B. Lynch*)

District	*Period of records*	*Dry-matter production (lb. per acre)*					
		Winter	*Spring*	*Summer*	*Autumn*	*Total*	*Range*
Dargaville . .	5 yrs.	2,200	5,000	5,020	3,350	15,570	11,020–19,050
Hamilton . . .	7 ,,	1,460	4,270	2,410	1,840	9,990	7,950–14,150
Stratford . .	6 ,,	480	2,120	2,020	1,480	6,100	5,100–7,400
Hawera . . .	7 ,,	1,290	2,760	2,560	1,570	8,180	6,500–9,350
Marton . . .	14 ,,	890	3,140	2,145	1,400	7,500	4,500–8,800
Gisborne . .	9 ,,	2,320	4,070	3,130	2,730	12,250	10,500–14,550
Winchmore (dry) .	4 ,,	180	1,780	1,750	410	4,110	2,350–5,900
Winchmore (irrigated)	4 ,,	200	2,360	3,660	820	7,050	5,150–9,650
Invermay . .	3 ,,	430	3,020	3,270	1,100	7,820	6,100–9,150
Winton . . .	12 ,,	290	3,100	3,510	1,560	8,480	4,750–13,150

The capacity of pastures to restore fertility to soils exhausted by cropping was investigated at Grasslands. The areas used for the experiments referred to earlier in Fig. 3 were cultivated and sown in two crops, rape and maize, selected on account of their high and rapid demands on soil nutrients. Marked differences appeared in the soil texture and colour when the area was ploughed. In the clover plots, the soil was dark in colour and open in texture. In the grass plots the furrow had a distinct glaze and a sticky texture. The following figure (Fig. 4) shows how the yield of rape was closely associated with the yield of the pasture sward which preceded it.

The fertility built up by the pasture was short lived, for in a second crop of rape little difference occurred between the yields in the various strips.

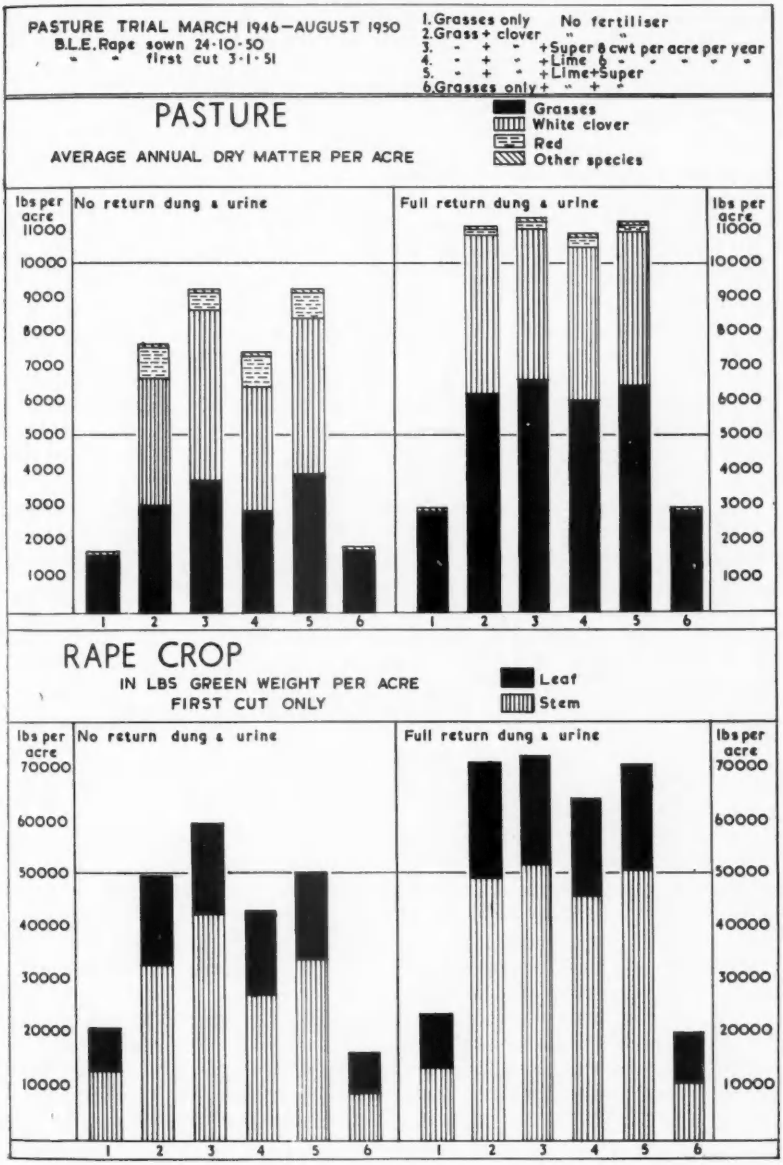
PASTURE TRIAL MARCH 1946—AUGUST 1950
B.L.E. Rape sown 24·10·50
" " first cut 3·1·51
1. Grasses only No fertiliser
2. Grass + clover " "
3. " + " +Super 8 cwt per acre per year
4. " + " +Lime 8 " " " " "
5. " + " +Lime+Super
6. Grasses only + " + "
PASTURE
AVERAGE ANNUAL DRY MATTER PER ACRE
Grasses
White clover
Red
Other species
lbs per acre
No return dung & urine
Full return dung & urine
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
1 2 3 4 5 6
RAPE CROP
IN LBS GREEN WEIGHT PER ACRE
FIRST CUT ONLY
Leaf
Stem
70000
60000
50000
40000
30000
20000
10000

FIG. 4

The results of this study have an important application over wide areas where the soil has been exhausted by persistent cropping.

Top-dressing of Pastures

Early in New Zealand's agricultural history, chemical analyses of soils indicated that phosphorus deficiency was widespread. Enterprising farmers, particularly in the Waikato district, ventured to use various phosphatic fertilizers on pastures and the variable promise shown by these applications revealed a number of points requiring investigation. Hence the first systematic fertilizer trials were inaugurated by the Department of Agriculture at Marton in 1928.

From the results of 8 years' work on the Marton plots, using and developing mowing and grazing techniques, Hudson and his co-workers showed that the best fertilizers were capable of raising production from 3,500 lb. to some 5,250 lb. dry matter per acre. Superphosphate and lime applications generally proved superior to basic slag and North African phosphate, while the improvement in yield was shown to be due largely to increased growth which occurred at the low-production periods of the year. Fertilizers applied frequently gave better returns and a better spread of pasture growth throughout the year, a finding which inspired farmers to top-dress their pastures sometimes three or four times a year. Recognition of the low nitrogen status of most soils at this time aroused much interest in the possibilities of using nitrogenous fertilizers as well as phosphates. Ammonium sulphate was tested in the Marton experiments, and gave improved growth for short periods, particularly summer and autumn applications. However, it appeared to produce a harsh type of pasture, and a decided falling off (slumping) in growth occurred after peaks of high production. Potash gave only very slight increases.

The results of these trials answered many of the questions then being raised and set the pattern for top-dressing practices which have followed since.

In a very much drier environment at Ashburton, in the South Island, similar trials conducted by A. H. Flay showed that 4 years of regular applications of superphosphate were necessary to increase the grazing capacity of a pure Danthonia sward from one to two dry sheep per acre, whereas with clover present an increase of from $1\frac{1}{4}$ to 3 dry sheep was attained in 1 year, thus emphasizing the importance of the clover constituent of the sward, even in dry regions.

The value of lime applications to pastures was experimentally determined in trials at Marton which were concluded in 1941. The main questions concerned fineness of grinding, the relative merits of hard and soft limestones, rates and frequencies of applications. Doak, Elliott, and Lynch investigated these matters and the results of their work showed that limestone ground to a fineness that permitted 50 per cent. to pass through a 30-mesh screen was satisfactory; that the hardness factor of limestone was immaterial; that finely ground limestone gave most rapid results; and that heavy (1 ton per acre) initial applications of ground

limestone followed by similar applications at intervals of 3 to 4 years gave best results in pasture growth.

The question was often raised as to what happened to the applications of phosphates and lime which were applied regularly to pastures, and Doak, using the Marton plots, found that after 8 years of continuous top-dressing, noticeable movement downwards of phosphates occurred into the 6–10 in. layers of soil. Applications of calcium carbonate retarded this downwards move of phosphate when superphosphate or rock phosphate was used, but not in the case of basic slag. Akin to the fate of phosphate and lime dressings was the problem of their effect on other mineral constituents of the soil. Investigations of Waikato soils, where superphosphate top-dressing had been regularly practised for some years by J. K. Dixon and N. H. Taylor, showed that losses of exchangeable potash and magnesium occurred, a fact that was then thought to have a possible association with grass staggers (hypomagnesaemia), a stock disease prevalent in the district.

Meantime top-dressing of pastures has become a normally accepted farm practice throughout New Zealand. Applications of the order of 2–3 cwt. are applied annually, once the phosphate content of the soil has been brought up to the level appropriate to the soil type. The Rukuhia Soil Research Station of the Department of Agriculture has from numerous tests established the phosphate fixation of many soil types, and this serves as a guide to farmers seeking advice. To an increasing extent, as deficiencies in trace elements are located, elements such as cobalt, molybdenum, copper, or iodine are being added to the superphosphate top-dressing. From the combined researches of the Soil Bureau and the Extension Division of the Department of Agriculture, areas responsive to lime, phosphates, and potash are being kept under constant review. This proved valuable when aerial top-dressing was initiated, for it indicated those hilly areas where response from superphosphate could be most readily secured without lime, the weight of which was excessive for application by aeroplane.

Aerial top-dressing. Nothing has been so spectacular in its influence on pastures in recent years as the expansion in the use of the aeroplane for top-dressing hill-country pastures. Of 8,240,000 acres top-dressed in 1955, some 3,854,000 were done by aeroplanes using almost one-half of the fertilizers manufactured in the Dominion. The aeroplane has in a decade become New Zealand's most important farm implement, developing pastures in terrain which could never have been dealt with by wheeled implements, and arresting the advance of deterioration which was so evident previously in hilly regions.

At present the New Zealand farmer's bill for top-dressing his pastures is of the order of some £10,000,000 annually. It may be said too that much of this top-dressing has been applied uncritically for years past. Investigations by Elliot and Karlovsky at the Soil Research Station, Hamilton, have defined the optimum phosphate levels for three common Waikato soil types. In order to maintain these levels, annual application of 2 cwt. superphosphate on the Hamilton, 3 cwt. on the Ohaupo, and 4 cwt. on Horotiu have been found necessary to maintain

maximum dry-matter yields from pastures growing on these three types.

These investigations no doubt point the way to the future trend of fertilizer research in which progressively more precise information will be sought.

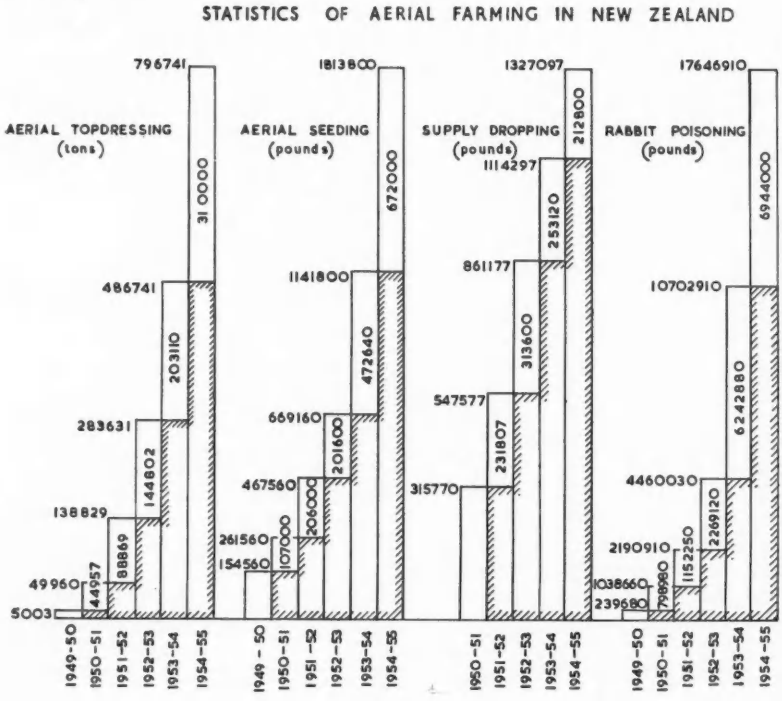

FIG. 5

Miscellaneous Researches Concerning Grassland

It is possible to make only the briefest mention of a number of other important grassland researches undertaken during the past 25 years.

The occurrence of seasonal dietary upsets on grazing stock have directed attention to the HCN, iodine, and non-protein nitrogen metabolites present in pasture, which may be the causes of such ailments as grass staggers, bloat, and facial eczema. A measure of success in the control of bloat has been attained by the use of anti-frothing agents such as peanut oil, and with penicillin.

An outstanding achievement has been the conquest of two very destructive insects, grass grub and grass caterpillar, which have caused annual losses of over £1,000,000, by the use of DDT and Gammexane following extensive field and laboratory trials.

As the result of much field and laboratory research many 'problem' soils

where pasture establishment was once considered impossible now carry excellent swards. This applies to vast areas of pumice soils which have responded to generous cobaltized phosphate applications and the use of pedigree pasture seeds in which white clover establishment has been assisted by special rhizobia cultures. Large areas of raw peat are being converted from scrub to pasture by appropriate drainage, generous liming, phosphate, potash, and copper top-dressing, now that research has revealed the fundamental nature and needs of such peat. Hill-country pastures in both Islands have had their stock-carrying capacity raised 20 per cent. by fencing alone to ensure better utilization of herbage, while the introduction of clovers and phosphate top-dressing has shown a further increase of 20–30 per cent.

More recent ecological studies carried out in cabinets and glasshouses with close control of lighting, moisture, and heat have revealed the responses of and the tolerances to variations in these three factors, shown by the principal grass and clover species grown in New Zealand. Associated with microclimate studies at widely separated field stations, it has become possible to forecast, with a good degree of reliability, the production which should be expected from any species when growing in any district.

Conclusion

For New Zealand, the past quarter-century has seen a remarkable expansion and development of grassland scientific activity from the foundations of a small permanent staff of research workers, experimental areas, and laboratory facilities laid in the 5 years preceding 1933.

Extensive field ecology studies and the farm practice of top-dressing appear to have been the two origins from which a wide array of research activities have sprung, to develop into prominent spheres of research using, to an increased degree with the progress of years, the fruits of fundamental research derived from biology, chemistry, and physics.

A review of the period has shown the outstanding importance of clovers as nitrogen gatherers, under the stimulus of phosphates, building up soil fertility so that pastures comprising the best strains of grasses could be developed and maintained. Selection and breeding brought improved pasture species which have done much to increase total dry-matter yield and to extend its season of production. Pastures composed of these improved species have shown their increased adaptability under the many systems of grazing management required in different types of farming. The soil-fertilizer-plant-animal combination has resulted in the building up of soil fertility simultaneously with increased carrying capacity. With the solution of existing problems, new ones arise. While significant progress has been made in such fields as bloat, facial eczema, blind-seed disease of ryegrass and others, they still remain unsolved. While at the beginning of the period under review one of the main problems was the low protein content of pastures, today many suspect that much of the shortcomings of pastures, as revealed in the thrift of grazing animals, may be attributed to diets over-rich in protein.

The past 25 years have seen the establishment of a science of grass-

land research with its corps of biologists, chemists, and agriculturists, who have assisted in bringing about in this period a revolution in which pasture has been raised to the status of a remarkable crop, utilized for soil conservation, soil-fertility improvement, and increased farm production. This corps of scientists has, through maintaining close association with the farming community, promoted the implementation of the advances made over wide areas of the Dominion, and itself now faces a series of problems of increasing complexity but of great promise when surmounted.

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ADVANCES IN CROPS AND PASTURES IN THE UNION OF SOUTH AFRICA IN THE LAST TWENTY-FIVE YEARS

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HOWEVER desirable it may be, when sketching progress in crops and pastures in a particular country, to acquaint the reader with the physical and human background, it has not been possible to do so in this short article. Important aspects are merely mentioned, and some sources of information are indicated [1, 2, 3, 4].

Apart from specific advances in crops and pastures, progress in other fields has also contributed much. In this connexion must be mentioned effective planning and exercise of the administrative function by the Department of Agriculture. The extent of these may be gathered by referring to the Annual Reports of the Secretary for Agriculture [5].

Extension services based on the findings of research have been improved, and farmers have been provided with free advice on farm-planning and operation. Increasing numbers have attended courses in agriculture either at the Agricultural Colleges or at one of the three Universities providing degree courses in agriculture.

The passage of the Marketing Act (Act No. 26 of 1937) set up the machinery to ensure orderly marketing and to maintain satisfactory price-levels even during periods of depression [6].

Probably no single factor has changed the agricultural pattern of the Union more than the disappearance of the ox as a draft animal and its replacement by the truck and the tractor. In common with the rest of the world, mechanization has revolutionized many agricultural operations. It has enabled crops to be planted expeditiously to take advantage of favourable weather conditions or to avoid unfavourable ones. It has undoubtedly contributed to increased volume of production, if not actually to higher yields per acre. Mechanization has provided a substitute for farm labour which has migrated from farms to industries [7].

Although the vagaries of weather and climate in South Africa have been the subject of comment from earliest times, the first serious official recognition of their significance in agriculture followed the Final Report of the Drought Investigation Commission in 1923 [8]. Shortly afterwards Leppan [9] drew attention to the influence of climate on the pattern of agricultural development in arid and semi-arid regions and a number of publications on weather and crops followed [10, 11, 12, 13].

Since that time studies on the interrelationships between climate, vegetation, and soil erosion have increased. A Section of Agro-climatology has been established in the Division of Crops and Pastures of the Department of Agriculture, and a number of agro-climatologists have been appointed at various Agricultural Research Institutes. Research is now being encouraged and co-ordinated by a Departmental Com-

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mittee. The study of soil erosion and its many problems has resulted in the passage of the Soil Conservation Act which now forms the basis for land utilization on a conservation basis [14].

The statistical approach to agricultural experimentation [15, 16], perhaps more than any other factor on the scientific side, has made field research more effective. In 1929 a course in biometry and experimental methods was introduced in the Faculty of Agriculture of the Transvaal University College (now the University of Pretoria). A chair in biometry has since been established at the Natal University, and posts are being contemplated at the other Universities with agricultural faculties. Practically all research workers in crops and pastures are today acquainted with statistical techniques, and consulting statisticians are attached to some of the Divisions and Research Institutes.

The field in which agronomic research operates is necessarily very wide, and it impinges on the terrain of many basic and applied sciences. To deal more than superficially with advances in but a few of these would be impossible in an article such as this.

Advances in Crops

Crop-production techniques

During the past two or three decades some important papers have appeared on cropping practices such as: monoculture, fallowing, crop rotation, green manuring, and companion cropping [17, 18, 19, 20, 21]. In these studies monoculture has been found to lead to soil deterioration. Fallowing has been shown to be of no material benefit under summer-rainfall conditions. Crop rotation with annual non-leguminous crops has given results which were probably due to slight non-permanent alterations in the supplying power of the soil. On the other hand, crop rotation with legumes was generally beneficial. The main advantage of crop rotation appeared to be due in some instances to better disease or pest control. Green manuring was shown to be uneconomic, and companion cropping limited in its application.

Some practices and techniques which have contributed to progress in crop production have been the outcome of specific research, others have been discovered in the course of practical farming. Only a few of the more important of these practices can be mentioned. They include improved soil management practices with the object of achieving better seed-beds; more effective moisture conservation and weed control; replacement of the mouldboard plough by other soil-stirring implements; the use of trash layers and stubble mulches; the use of more fertilizers; the use of 7-foot rows to aid mechanical control of weeds in row crops; and the use of hormone-like selective herbicides; the use of better-adapted, better quality agricultural seed; more effective control of plant diseases by means of seed treatment; insect control by means of systemic and other insecticides; the application of conservation practices to prevent loss of soil and to conserve moisture; the introduction of grass leys in rotation with annual crops.

Soils and fertilizers

South African soils, especially in the Summer-rainfall Area, have not been under cultivation for very long, and the fertility pattern is still changing. Soils in the maize-producing areas of the Highveld are now beginning to show signs of deterioration due, it is thought, to depletion of organic matter, accompanied by soil acidification and possible micro-element deficiencies.

Some important fundamental contributions in the field of soil technology have been: the classification and description of soil groups and sub-groups of South Africa published by C. R. van der Merwe [22]; studies on the clay minerals of South African soil groups by van der Merwe and Heystek [23, 24, 25, 26]; and the study of the effects of plants on the mineralization of nitrogen and the maintenance of organic matter in the soil by Theron [27], which is a basic contribution to the knowledge of how a grass ley may function.

Most of the published work on soil fertility has been confined to the assessment of fertilizer requirements of field crops. As far back as 1903 field experiments with maize were started at Potchefstroom [18]. Practically all the experimental results obtained with maize have led to the conclusion that annual dressings of about 200 lb. per acre of superphosphate were all that were needed for satisfactory crop yields [17, 18, 19, 20, 21, 28, 29, 30, 31].

Nitrogenous and potassic fertilizers, except in a few isolated instances, appeared to be without much effect [32]. But subsequent research, inspired by work in the United States, showed that nitrogenous fertilizers could be of great importance with high population densities. The interaction between plant numbers and fertilizer use has opened a new approach to fertilizer practices [33].

In the Winter-rainfall Areas, Slabber and Sim [34] reported that good responses were obtained from superphosphate applications to wheat and other winter cereals. In addition small dressings of nitrogenous fertilizers were beneficial. Other contributions of importance on fertilizer practices were papers by Henning *et al.* [35] and Steenkamp [36] on Virginia tobacco, Dodds [37, 38] and Sherrard [39, 40] on sugar-cane in Natal, and Turpin and McKellar [41] and van Garderen [42] on the use of fertilizers on irrigated lucerne.

The abnormal symptoms in maize associated with soil deterioration on the Highveld have been ascribed by Viljoen [43] to a zinc deficiency. Other workers have considered that the condition is due basically to depletion of organic matter as a result of long-continued cultivation with annual crops. If the latter view is correct it would seem that, in addition to palliative treatments, cropping practices should be improved by resting the soil with perennial grass leys.

Plant breeding

A. R. Saunders succeeded in developing drought-hardy types of white dent maize, and produced the synthetic varieties of maize known as 'Anveld' and 'Synthetic Potchefstroom Pearl'. Some of the lines and

genetic material which he produced have since been used in the production of hybrid maize.

The work on hybrid-maize breeding was organized on a national basis by F. X. Laubscher with headquarters at Potchefstroom and plant breeders at other Research Institutes co-operated. The top-cross (Potchefstroom Pearl × K64) developed at Potchefstroom is capable of an increase in yield over the old varieties of between 25 and 30 per cent., especially in dry seasons; it is susceptible to leaf blight (*Helminthosporium turcicum*) and may suffer considerable damage in moist seasons; about 2,500 tons of seed of this top-cross are produced annually. A white double-cross dent (SA5) producing about the same yield as the top-cross but more resistant to leaf blight, as well as a yellow dent double-cross (SA4) have also been produced at Potchefstroom. Two white dent top-crosses (SA7 and SA9), using a single-cross parent adapted to Natal conditions and yielding well, have been developed at the Natal Agricultural Research Institute, Pietermaritzburg. A yellow flint double-cross (SA200) which is early maturing, high yielding, and adapted to the eastern Free State has been produced at the Bethlehem Agricultural Research Station [44, 45].

Saunders also developed upright varieties of cowpeas and selected types resistant to eelworm and leaf spot. His work on soya beans resulted in the development of non-shattering types adapted to local conditions. A variety of grain sorghum known as 'Radar', resistant to witchweed (*Striga lutea*), was developed by him.

Laubscher, while working at Potchefstroom, studied the genetic relationships of a large number of sorghums [46]. He produced a superior sweet sorghum type suitable for ensilage, under the name of 'Haakdoorn'.

The breeding of winter cereals has always been a major project in the research pattern of the Winter-rainfall Area. Many of the varieties which were grown two or three decades ago have since been replaced by new varieties [47, 48]. The improved varieties show marked advantages in respect of disease resistance, baking quality, earlier maturity, better adaptation to changed conditions, and higher yielding ability [49]. The progressive improvement of varieties of wheat and other winter cereals suited to conditions in the Winter-rainfall Area has been due mainly to the work of J. N. Neethling [47, 48] and his associates and students. This work ranks amongst the most important of the advances made in crop production in the Winter-rainfall Area during the past 25 years.

Research work which has accompanied the introduction of the lupine (*Lupinus* spp.) has included the collection and testing of varieties from all parts of the world. High-yielding strains of both the sweet and the bitter types of the species (*L. luteus* and *L. angustifolius*) have been isolated. Non-shattering and soft-seed-coated strains have also been selected. The bitter lupine has been found to be suitable both as a grazing crop and as a seed crop for feed for sheep; it is not liked by cattle, however. The sweet lupine may be used as a silage and as a seed crop, but it is not practicable to use it for grazing; because of its high palatability it is easily overgrazed and damaged [50].

Progress in wheat breeding for the Summer-rainfall Area was due largely to Laubscher, who succeeded in developing adapted varieties showing disease resistance and drought hardiness. In 1951 and 1952 four new varieties suitable for summer production were released under the names 'Goudveld', 'Spitskop', 'Penkop', and 'Magaliesberg' [51].

Other contributions were the introduction from Abyssinia of brown- and white-seeded strains of tef (*Eragrostis tef*) by Leppan, and their subsequent selection study, multiplication, and distribution by Pullen and Haylett at Pretoria [52].

The cotton industry started just after World War I. Research work began at this time at Barberton in the eastern Transvaal and at Rustenburg in the western Transvaal. The limiting factors in cotton were inferior quality, insect pests, and diseases. Breeding work aimed at eliminating these disabilities. The first jassid-resistant variety was released in bulk in 1929. This was a selection U4 by Parnell from the Uganda variety. A further selection from U4, known as 5143, with improved yielding ability and lint-length was grown in the eastern areas until 1947. This was replaced in southern Swaziland and northern Natal by a 5143 × Cambodia hybrid. In other parts of the eastern area A618 replaced the former varieties in 1950. The selection A7215 now being grown is variable in quality and not well adapted. Efforts are being made to replace this with better selections which are also resistant to Verticillium wilt and bacterial blight.

A. R. Pullen developed from Improved Bancroft a strain known as 'Rustro' which became the standard variety in the comparatively jassid-free western areas. The cotton work was discontinued at Rustenburg during the depression of the 1930's.

At Upington and on the Settlements along the Orange River, Improved Bancroft is being grown, and selections from this variety are being tested by O. Kapp and other plant breeders.

The efforts of both plant breeders and entomologists have not been very successful in devising control measures for the bollworm and other insect pests, but the compulsory close season introduced in the Barberton District in 1949 has proved effective against some of the pests. The close season ensures that no ratooning takes place, and all cotton plants have to be destroyed by a certain date after harvest [53].

Tobacco and other crops

The Virginia tobacco crop has been the subject of well-organized production methods and research. Its destinies are controlled by the Tobacco Control Board with compulsory marketing through various co-operative societies acting as agents of the Board. The industry has its own Central Tobacco Research Station at Kroondal near Rustenburg, which came into being in 1937, and acquired full status as a Specialist Research Station in 1952.

A highlight in the progress of the industry as a result of intensive research was the replacement of the unpopular flue-cured variety Amarelo by the well-known Orinoco type, and the prohibition of

production of the former since 1952. This change will make it possible for the Union to dispose of any surplus over its own local requirements.

Other steps which have contributed to the progress of the industry are: the expansion of flue-cured tobacco from insignificant amounts in 1930 to its present annual production of 20 million lb.; the change-over from a dark, heavy tobacco to a light-coloured type; improvements in cultural methods, fertilizer practice, and other aspects of field techniques; the breeding of new strains resistant to mosaic; progress in biochemical and physiological research; effective control of nematodes by dichloropropane-dichloropropene (D.D.) and ethylene dibromide (E.D.B.) and of many insects by means of systemic poisons; the control of *Oidium tabaci* by means of karathane has been accomplished.

A mobile laboratory operating from the Central Tobacco Research Station is available for the assistance of growers in distant parts [54].

Whilst large amounts of wheat have been grown in the cooler and moister parts of the Summer-rainfall Area attention is also being given to the cultivation of so-called summer wheat during the hot summer months. Considerable success has been achieved but the practice is not without danger from rust which might at any time develop into epidemic proportions. A spectacular expansion in groundnut production and also, to a lesser degree, increase in sunflower and castor-bean production has also occurred during the last 10 years. Owing to inability to import grain bags from the East such fibre crops as hibiscus (*Hibiscus cannabinus*) and sisal (*Agave sisalana*) are being grown.

Advances in Pastures

Natural vegetation suitable for grazing covers about 90 per cent. of the Union's total of 472,550 square miles. The potential of this area for the production of pastoral products under proper management is vast.

The natural vegetation of the central part of the Summer-rainfall Area is predominantly grass. This covers the southern Transvaal, most of the Free State and Basutoland, western Natal, and the north-eastern Cape. Owing to a combination of moisture and high temperatures there is a vigorous summer growing season. This alternates with a dry, dormant winter period resulting in a fluctuating feed supply. The grassland area is one of mixed farming where crop production occupies an important position. Savannah vegetation encircles the central grasslands on the east, north, and west. The proportion of trees to grass is determined by the amount of rain and the temperature. Ranching takes place in these parts, and in the warmer low-lying areas where frost is absent subtropical fruits and crops are grown.

The region of all the year round rainfall is located on the boundary between the Summer- and Winter-rainfall Areas. It follows a line stretching from Knysna on the south coast to the intersection of the 24th parallel and the coast-line on the west. At the south coast the rainfall is high and adequate for the production of most summer and winter crops, but the soils are poor and the topography uneven. Some of the few indigenous forests of the Union occur in this area. As one proceeds towards the interior the rainfall diminishes rapidly, and the vegetation

changes to that typical of the Karoo. The Karoo is in the transition area between the Winter-rainfall Area in the south and the Summer-rainfall Area in the north, but owing to its extreme aridity rainfall distributon loses much of its significance. The vegetation of the Karoo, consisting of short, succulent, or arid bush types, is particularly suitable for raising merino sheep. Practically no crops are grown in the Karoo except under irrigation [55, 56].

In 1933 a section dealing specifically with pasture problems was established within the former Division of Plant Industry of the Department of Agriculture and Forestry headed by I. B. Pole Evans. J. D. Scott, now professor of pasture management at Natal University, was appointed as the first pasture research officer of the Department. This appointment was followed by that of J. Rowland and many others, and at the present time there are thirty-five research officers at thirty agricultural research institutions in the Union including chairs in pasture management at the universities in the Summer-rainfall Area.

Some of the first experiments on veld management were those carried out at Groenkloof by Pole Evans and Phillips mainly to study ecological changes in veld [57]. Work on pasture grasses was also started at about the same time at Prinshof in Pretoria [58]. During the course of the work at Groenkloof, Pole Evans demonstrated the high carrying capacity which could be achieved from established pastures of indigenous grasses, and these findings attracted considerable attention at the time.

Pole Evans and his associates, notably van Rensburg, besides devoting much time to botanical surveys, collected grasses within and beyond the borders of the Union and studied the suitability of many different indigenous and exotic grass species for pasture purposes [59].

During the late 1930's a number of pasture research stations were established in various parts of the country at the instigation, principally, of Pole Evans. The first projects started at these stations were devoted to survey studies, development of grass nurseries, and later to field experiments designed to ascertain the relative importance of factors in veld management such as rates of stocking, the effect of mowing and grazing, the duration of rest periods, rotative grazing, fertilizer use, burning, mowing, bush encroachment, and changes in botanical composition and basal cover. Much of this work was recorded in the several progress reports published at that time by the Department of Agriculture [60].

The emphasis placed by Pentz in 1938 on the use of botanical surveys to assess correct land use began to attract attention [61]. This concept was elaborated later by him in an agro-ecological survey of Natal which today provides the basic pattern of land use based on conservation methods in that Province [62].

By the mid-1940's research in pasture management had progressed considerably. Attention was now being paid to the integration of factors in pasture husbandry to provide proper systems of range management. Irvine, working at the Towoomba Research Station, devised a range-management system suitable for the Transvaal Bushveld [63]. Scott and Pentz developed range-management systems for Natal [64], whilst

Botha worked along similar lines at the Athole Pasture Research Station in the eastern Transvaal [65] and Preller in the western Transvaal [66].

Useful reviews of various veld-management systems in South Africa were published in 1947 and in 1951 by Scott [67], whilst Morris reviewed the results of pasture research that had been done at the Potchefstroom Agricultural College between 1941 and 1945 [68]. Meanwhile Tidmarsh, who was working on the utilization of Karoo and semi-desert vegetation, succeeded in formulating policies of range management for these drier areas [69].

Other aspects of pasture research have resulted in valuable contributions: in the field of range ecology, development of the wheel-point method of measuring vegetation, devised by Tidmarsh and Havenga [70] and its subsequent refinement by Havenga [71], need special mention. The breeding and selection of indigenous grasses and legumes for various purposes including leys and mixed established pastures has received attention. Promising results have been obtained from intersowing veld with clovers without mechanical disturbance of the soil. The study of grass and grass-legume mixtures for dryland and for irrigated pastures has been the subject of intensive investigation. The Department of Agriculture has established a station at Rietondale for the introduction, testing, multiplication, and distribution of propagating material of recommended pasture plants.

A significant step in pasture research in the field of plant survey and ecology culminated in the publication in 1953 by Acocks of a map of veld types, with a discussion of the author's views on the possible changes that may have taken place in plant succession [56].

Another milestone was the appearance of a book *The Grasses and Pastures of South Africa* in 1955 [72]. This work consisted of two parts: the one, a guide to the identification of grasses in South Africa by Lucy Chippindall, was a well illustrated systematic study covering more than 500 pages, the other was a compilation by nineteen leading contributors who discussed important aspects of pasture management in South Africa.

No review of progress in pasture research would be complete without reference to the pioneer work in this field of African Explosives and Chemical Industries, Ltd. As early as 1929 this company began to take an interest in veld management and fertility experiments. By 1932 the area covered by these experiments had extended to over 1,000 acres scattered over the high-rainfall areas of the Union. Additional experiments were added each year, and by 1935 over 2,000 acres were involved. About 5 per cent. of the area was devoted to experiments with planted exotic and indigenous grasses. Most of this work was preliminary in nature and was discontinued after 1935 except for a few critical experiments at Umbogintwini in Natal and at Frankenwald near Johannesburg [73].

In 1936 African Explosives and Chemical Industries, Ltd., seconded Lindsay Robb to the Transvaal University College to conduct research on various aspects of veld management. This work was considerably reduced during the war and was later discontinued [74].

Working with turf grasses Hall and Moses [75] established the fact that grass when intensively defoliated required higher dressings of fertilizers than would be used normally by annual field crops. They also demonstrated the importance of nitrogenous fertilizers for grass. Results of various co-operative and other experiments were published by Hall [76, 77], Hall and Moses [78], Hall and Meredith [79, 80], and Hall, Meredith, and Murray [81, 82]. These demonstrated that commercial fertilizers increased the carrying capacity of veld, raised the protein and phosphorus content, improved palatability, reduced the percentage of bare ground, and encouraged the more valuable grasses. A comprehensive review of this work up to 1947 was also published by Meredith [83].

Recent critical work by officers of African Explosives and Chemical Industries, Ltd., provided additional quantitative evidence of the benefits which could be expected from well managed veld dressed with fertilizers. These also included an evaluation of the extent to which milk yields could be increased on pasture treated with fertilizers and the degree to which the quality of milk could be improved [84]. In addition to this work specifically related to agriculture, important contributions were made by the organization in the field of turf management for sporting purposes [85].

Research on leys since 1938 has been in progress at the University of Pretoria where the first field experiments with Rhodes grass (*Chloris gayana*) in rotation with arable crops were commenced by Haylett [86]. This preliminary work led to the establishment of a large-scale 30-acre demonstration plot with a 4-year grass-lucerne ley followed by maize and legumes. The demonstration was a closed unit with dairy animals to provide the animal factor, and has served to establish the practicability of this method of land use.

During the progress of the unit demonstration, plot, laboratory, and lysimeter studies were in progress, and these provided the bases for Theron's [27, 87] contributions on leys. This work was supplemented by field studies on the use of fertilizers on grass and its effect on maize following, published by Theron and Haylett [88, 89].

Much work is still required to determine which grasses and mixtures are best suited to conditions in other parts of the country and how these should be established, managed, and utilized to best advantage. In spite of the fact that knowledge on leys is still limited the Government has decided to subsidize ley farming, and the view is held that a combination of arable and ley farming offers greater promise of keeping soils permanently productive than others at the present time.

Advances in Crops and Pastures in the Winter-rainfall Area

The climate of the Winter-rainfall Area in the extreme south is Mediterranean and more than 50 per cent. of the precipitation occurs during the winter. The summers are hot and dry. The typical vegetation of the Winter-rainfall Area is schlerophyll with comparatively little grass. The grazing value of the natural pasture is low and is entirely given over to sheep and goats. Veld management is not an important

consideration, but established pastures especially under irrigation are gaining in popularity.

Twenty-five years ago arable cropping was confined to the production of winter cereals—wheat, oats, barley, and rye. Of these wheat has always been the most prominent. The other winter cereals which were alternated with wheat were sometimes used for animal feed, but the numbers of livestock which could be supported on grain farms were few. Many of the wheat lands had been under cultivation for several centuries, and yields had declined to only two or three bags of wheat per acre [90]. Much of the arable land was allowed to lie fallow each year. Farmers were hard-pressed to maintain production even on this low plane, and the country was becoming gravely concerned both at the rapid rate of deterioration of Western Province soils and at the resultant threat to future bread supplies. To achieve even this modest production per unit of land it was necessary to fallow and to rotate the wheat crop with other small grains. Such rotations were generally short-term ones of two, three, or four courses. Examples of these were wheat-fallow, oats-fallow, wheat-oats-fallow, and wheat-fallow-oats-fallow [91]. None of these rotations could be expected to contribute much to the maintenance of organic matter, soil fertility, or soil structure. In fact the effect of the fallow and of alternate cropping with annual crops was mainly to allow time for the soil to recover its supplying power after temporary exhaustion by the wheat crop. This system of rotation was fundamentally exploitive.

Whilst this deterioration was taking place the food needs of a growing population were also steadily mounting—a fact which urged farmers to attempt to produce more wheat on already worn-out lands and to extend their activities to new land in marginal areas. The prospects did not appear encouraging.

Introduction of dryland lucerne

As far back as 1913 efforts were made to grow lucerne as a dryland crop with little success at first. As a result of persistent efforts of the staff of the Stellenbosch-Elsenburg College of Agriculture it was eventually found possible to grow lucerne satisfactorily on drylands [92]. This provided simultaneously both a perennial and a legume with which wheat could now be alternated. At the same time it furnished a hay and grazing crop which enabled more livestock to be introduced.

By 1925 dryland lucerne had become a regular feature of the farming system in the eastern part of the Winter-rainfall Area [93]. As more knowledge was acquired the area of successful cultivation was extended, and it is now possible to grow dryland lucerne even on originally acid soils when properly limed, inoculated, adequately prepared, treated with fertilizers, and suitably managed [94]. The discovery that lucerne could be grown successfully as a dryland ley crop under a wide range of soils and climate was a major advance in crop production in the Western Province.

The short-term rotations with fallow and non-leguminous annuals were replaced by long-term rotations stretching over periods of eight or twelve seasons [95, 96]. The 4-year lucerne ley provided a much needed

rest for the soil during which organic matter was given a chance to accumulate and the rhizobia in the nodules of the lucerne furnished nitrogen from the atmosphere. Conditions were thus created which enabled more livestock to be carried, and the manure in turn helped to improve the fertility of the soil.

The discovery that it was possible to grow lucerne for several seasons also stimulated interest in established pastures generally. This resulted in the introduction of subterranean clover [97]. The fact that more feed was available had in turn resulted in more and better livestock being maintained on Western Province grain farms today than previously.

The research which has accompanied this revolutionary change in land utilization has demonstrated that rotative cropping with lucerne leys has not only increased the yield of the wheat crop by 30 to 40 per cent. but also maintained the increased level of production for several seasons after the ley. Unfortunately the foot-rot disease (*Ophiobolus graminis*) is more severe after lucerne and this tends to reduce to some extent the beneficial effect of the ley [97].

Introduction of lupines

Since about 1936 a further advance took place with the discovery through experimentation that various varieties of lupines (*Lupinus* spp.) could be grown as dryland crops even on the more acid soils and in the drier parts of the Winter-rainfall Area where lucerne was less successful [96, 97]. It is estimated that about a quarter of the land in the drier north-western part of the Winter-rainfall Area is now under lupines. This legume crop is not only suitable for alternate cropping with wheat or oats but also provides feed for large numbers of sheep and dairy animals.

When used in rotation with wheat, lupines have an immediate beneficial effect on the subsequent crop but exhibit little residual advantage. Green manuring with lupines is not considered economic. It has also been found that spring cultivation of fallow land when the soil is moist has produced a marked increase in the wheat crop which follows.

Other important advances

Aspects of progress in field husbandry which need be mentioned are: the storage of seasonal rainwater in earth dams and the more extensive use of river water for irrigation both of crops and established pastures; the making of ensilage from lucerne, lupines, and oats to bridge the feed shortages of the summer months and so to increase the stability of livestock farming [98]; the control by use of selective weedkillers of weeds such as wild vetch (*Vicia* spp.) and charlock (*Raphanus raphanistrum*) in wheat crops [99]; the application of improved mechanization techniques and the encouragement of conservation farming methods under the provisions of the Soil Conservation Act.

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TRENDS OF AGRICULTURAL THOUGHT AND RESEARCH IN THE FEDERATION OF RHODESIA AND NYASALAND IN THE LAST TWENTY-FIVE YEARS

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THE three Central African territories of Southern and Northern Rhodesia and Nyasaland became federated in 1953. Much of the combined national income of the Federation comes from its mineral resources and the growing output of manufacturing industries. The proportion of national revenue stemming from agricultural sources is mainly through overseas sales of tobacco. Agriculture is otherwise largely concerned with the production of food for internal consumption and the value of agricultural exports is small, in comparison. Maize is a major agricultural product, forming the basic staple diet of the African population and being used extensively, too, in concentrate rations for livestock. Recently there has been a rise in maize production and a proportion of the crop has been exported. Agriculture, consequently, has largely centred round the production of these two major crops, tobacco and maize. At the present time, the increase in production of wheat, sugar, and potatoes is an important consideration when viewing the possibility of completing the picture of internal sufficiency in staple foods. The African is tending to consume more wheaten bread, particularly in the developing industrial areas. The production of beef and whole milk is largely internally consumed, and reasonably satisfies the internal market.

Considerable quantities of condensed, powdered, and skimmed milk and butter are imported. There is scope, therefore, for increased production of these, provided costs and price levels make their economic production possible. A small amount of good-quality beef is sold outside the country and this export could no doubt be increased, again provided the economic aspect is satisfactory.

Research, Education, and Advisory Services

Facilities for agricultural research have been developed mainly at the following centres:

Southern Rhodesia [1]

The Agricultural Experiment Station, Salisbury. This Station is situated in the northern portion of the town and has done extremely valuable plant breeding and agronomic work for more than 40 years. Maize, potatoes, groundnuts, sunflowers, cowpeas, soya beans, sweet potatoes, and wheat are the principal crops with which research is carried out, whilst the Station is the centre of hybrid-seed maize production, which is now extended to Panmure Breeding Station, near Shamva, about 50 miles north-east of Salisbury.

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Henderson Research Station. This lies some 17 miles north of Salisbury in the southern part of fertile Mazoe valley, which it serves in particular. An important part of the research carried out at this Station is concentrated on the integration of crops, animals, and pastures, whilst soil runoff and inland fish culture are studied.

Grasslands Research Station. This Station is situated close to Marandellas, some 50 miles east of Salisbury, and serves the higher rainfall areas of the country. The research here is concentrated on the intensive production of milk and beef from fertilizer-treated pastures on sandveld soils; veld management studies and crop experiments following grass leys are also in progress. There is a sub-Station at Melsetter, on the eastern border.

Gwebi College of Agriculture. The College is situated 18 miles west of Salisbury, in open, rolling country, at an altitude of 4,800 feet. It serves the three territories of the Federation for the education of young European farmers. (A similar College is planned for African students.)

The College farm demonstrates the integration of crops, pastures, and animals, and is highly mechanized. Excellent facilities exist for farm management and organization studies. The results of plant population-fertilizer studies with maize have given a useful guide to farm practice, whilst other trials are concerned with beef production from fertilizer-treated veld, and the management of these natural grasslands.

Sabi Valley Experiment Station. This Station is situated in the Sabi river valley, about 100 miles south of Umtali, in the low veld of the eastern border. The research here is mainly concerned with crop production under irrigation, and the study of soil management. Crops of special importance at this Station are wheat, cotton, and lucerne.

Matopos Research Station. This lies 20 miles south-east of Bulawayo, not far from the grave of Cecil Rhodes. This Station, together with the sub-Station at Nyamandhlovu, serves, in particular, the lower rainfall areas of the country. Hybrid-maize strains more suited to these areas are bred here, and also sorghums and millets for planting in the more arid areas. Large-scale cattle breeding and feeding experiments are conducted with a view to determining the best type of cattle to produce under Matabeleland conditions. Pasture research here is directed towards the finding of a management system for these conditions and which will increase the stocking rate of farms and ranches.

Pig Industry Board Research Station. This lies a few miles east of Salisbury and conducts studies of breeding and feeding of pigs, whilst litter-testing work is also in progress.

Gatooma Research Station. The main work of this Station concerns cotton breeding and the control of insect pests of cotton, whilst the general results of field husbandry experiments are useful for the midland area of Southern Rhodesia.

Kutsaga Tobacco Research Station. This Station is situated a few miles south of Salisbury, on sandveld soil. Together with the Trelawney sub-Station, 40 miles west of Salisbury, it is directed by the Tobacco Research Board of Rhodesia and Nyasaland. Tobacco culture in all its

aspects, including breeding, fertilizer application, disease control, and curing, is studied.

Chipinga and Karoi Demonstration Farms. These are controlled by the Federal Department of Conservation and Extension. Chipinga is near the eastern border, some 80 miles south of Umtali, and demonstrates the integration of crops, pastures, and livestock. The development of better farming in the area is largely due to the information passed on from this Station. The Karoi Station is situated on sandveld soil about 120 miles north-west of Salisbury, and serves much the same useful purpose as Chipinga.

The Stations described above are specifically concerned with the agriculture practised in the European areas. The Southern Rhodesia Department of Native Agriculture and Land Husbandry maintains a number of demonstration farms in areas devoted to African agriculture which are doing very useful work in showing the way to improved methods. Elementary agricultural education is provided for Africans at these centres and in special schools, such as Domboshawa, just east of Salisbury, and at various Mission centres.

Veterinary Research Laboratories, Salisbury. These are the centre of research into problems of animal health. Studies are in progress concerning infertility and abortion in cattle, mastitis control, and the parasites affecting sheep and cattle.

The University of Rhodesia and Nyasaland

A Faculty of Agriculture is being developed with its farm at Henderson Research Station mentioned above. London University degrees are taken at this multiracial institution.

Northern Rhodesia [2]

Mount Makulu Central Agricultural Research Station. This Station is situated a few miles from Lusaka and conducts a large programme of field experiments on various soils, and studies of beef production from exotic and indigenous breeds of cattle.

Mazabuka Veterinary Research Station. This Station is situated south of Lusaka, and carries out general veterinary work, whilst the availability of meat products from both African and European ranching is studied. African veterinary field assistants are trained at Mazabuka.

Elementary agricultural education is provided for Africans at Monze School, south of Mazabuka, and Lunzuwa School, near Abercorn in the north.

Nyasaland [3]

Lilongwe Agricultural Research Station. This Station is situated about 60 miles west of the southern shores of Lake Nyasa, and conducts an extensive agronomy programme including the production of hybrid-maize strains suited to the area, whilst long-term rotation experiments are in progress. The Colby School of Agriculture for Africans is situated here, whilst there is a further elementary agricultural training institution at Tuchela, near Mlanje, in the south.

The Federal Department of Conservation and Extension advises European farmers. Since the Second World War tremendous strides have been made by this Department, working in conjunction with Intensive Conservation Area committees, in soil and water conservation.

African agriculture is cared for by territorial Government departments.

Advisory services in the specialist subjects of botany, entomology, and chemistry are centred in the laboratories at the Salisbury Experiment Station.

As mentioned above, the development of the dairy industry is of vital importance, and the dairy branch of the Federal Ministry of Agriculture provides services which include inspection of factories and farms, grading of dairy produce, sampling and testing of milk, and general advisory work.

The organizations and centres so briefly described above have made great progress and contributed in no small measure to the agricultural progress of the Federation. Apart from the role which agriculture may play in contributing to the national revenue by exporting produce, in the future it will shoulder a growing responsibility for supporting the population of the Federation.

The present population of the Federation is estimated at between seven and eight million. It is thought that the African population will double itself by natural increase every 25 years, and the European population, with the aid of immigration, will double itself every ten years.

The following notes briefly describe a few trends of agricultural thought and research which may assist in providing the necessary advances in agricultural production, and refer to certain published works specific to various aspects of the problems concerned.

The Soil

This is of great variety, with pockets of greater fertility occurring in generally less fertile areas. The broad distinction, however, lies between soils of high and low clay content. The soils of high clay content are mainly associated with the production of grain and winter forages for human consumption and livestock feeds. The soils of very low clay content, popularly known as 'sandveld', are particularly suitable for tobacco production, because the intake of nutrients, particularly nitrogen, can be so adjusted that the all-important factor of ripening of tobacco leaf can be so controlled that effective and economic curing becomes possible. These are the natural factors underlying the most desirable apportionment of farming systems and types of production to specific areas, as far as the soil is concerned. Ellis [4–9] describes the background of soil types in Southern Rhodesia, whilst the Northern Rhodesian [2] and Nyasaland [3] reports give indications of the progress of knowledge in the two Northern territories.

Naturally, there can be no hard and fast line. Corby [10] has shown that through provision of organic matter and addition of nitrogen the sandveld can be adapted to food crops, particularly maize.

The Climate

The Federation has a wide variety of climatic conditions influenced by altitude and rainfall efficiency in different areas, altitude being closely linked with temperature. Much of the country is over 4,000 feet; certain areas of the great river valleys, notably the Zambezi and Sabi, which are being developed agriculturally, lie at about 1,200 feet. The Kafue Flats, in Northern Rhodesia, where a pilot 'Polder' scheme is in being, lie at about 3,200 feet. Land of agricultural potential in the Eastern Districts of Southern Rhodesia lies around 5,000 feet; that of the Blantyre-Zomba plateau in Nyasaland at 4,000 feet, and the high country at Nyika in the north of Nyasaland at 6,000 feet. The range of crops which can be grown is therefore wide, and the cooler areas are more suitable for the production of meat and milk from breeds of cattle of European origin, whilst in other areas breeds of cattle bred for many generations in warmer climes are better suited.

The predominant and controlling feature of the climate, however, is the strong demarcation between wet and dry seasons. Most of the rainfall is precipitated in five months, November–March. Apart, therefore, from the growing influence which irrigation facilities may have on farming, the whole agricultural economy must be geared to intensive production of human foods and provision for 'winter' feeding of livestock in this short period. To do this economically, on an increasing scale, demands the greatest efficiency on the part of the farmers. This efficiency depends on knowledge, emanating, through education, from observation, research, and discussion, and the common-sense application of this knowledge, by the farmers, to practical farming.

Apart from total rainfall, the incidence of precipitation and its relation, in various areas, with temperature, which, in turn, is conditioned by altitude, determines the rainfall efficiency.

Staples and Murray [11] briefly link the factors of soil and rainfall efficiency in their important paper on farming systems, for Southern Rhodesia. Studies of this nature continue, and naturally many adjustments of recommendations for specific areas will be made in course of time, and particularly in relation to the Federation as a whole, but this remains, nevertheless, as a basic example of the correct approach to problems of agricultural production in this part of the world.

Crops

The first half-century of European influence in the Federal territories has been characterized by the production of 'row-crops'. Maize, well adapted to the area, has become a staple food crop and tobacco an important product for export. Both are grown in rows.

Maize

Sansom *et al.* [12] deal with all aspects of maize production in Southern Rhodesia in a series of papers, read at a Conference in 1956, whilst from Northern Rhodesia Pawson [13] has reported interesting findings regarding soil fertility, and in Nyasaland [3] problems of variety and fertility are of importance.

The main approach to improvement in yield in all territories is through breeding, particularly of hybrid-maize strains, and studies of soil fertility and plant populations, whilst the effect of time of planting on yield has been closely observed.

The hybrid-maize programme initiated in Southern Rhodesia has met with singular success, and critical yield figures reported by Rattray [14–20] give evidence of substantial increases in yield potential. The hybrids so far produced are of somewhat shorter growth period than the open-pollenated parents from which they have been derived. This is a useful attribute when planting rains are late, because observation and experiment point to the value of early planting. Whilst the hybrids produced by Salisbury Experiment Station are suited to a wide range of European-farmed areas, they have not proved as suitable for some African peasant farmers, who store their maize on the cob in cribs, and this is readily attacked by grain-boring insects. The flint type of maize is more resistant to this insect attack than the other softer, dent type from which the Salisbury hybrids are derived, and hence one finds Nyasaland [3] carrying on its own breeding programme. The Matopos Research Station [12] has also initiated a hybrid-maize breeding programme because it is in the low-rainfall part of the country. General lack of resistance to *Helminthosporium turcicum* in the Southern Rhodesian inbred lines has recently necessitated selection of fresh material, with resistance an essential character. Attention has also to be given to the possibility of finding resistance to the common maize rust *Puccinia sorghi* and *P. polysora* and maize streak virus [12] particularly in the hotter areas such as the Sabi valley.

For many years soil fertility has been maintained in Rhodesia through the use of green-manure crops, and this is further referred to below. In post-war years the application of fertilizers to maize has been intensively studied, and a greatly increased use of fertilizers for maize has come about. In the past, phosphatic fertilizers have been regarded as of main importance; they remain, of course, of considerable importance, and even where the general phosphate status of the soil has reached a high level, farmers are advised to add sufficient for the requirements of a specific crop. The Chemistry Branch of the Federal Ministry of Agriculture has developed an excellent advisory system for farmers in this connexion, whilst their research [21, 22, 23] is revealing that the question is complex and involved. It is nitrogen which has come into prominence in recent years. Formerly it was thought that a leguminous green manure was the only worthwhile method of supplying nitrogen to a maize crop. Now, however, it has been found, over wide areas of the Federation, that the addition of nitrogen (normally in the form of ammonium sulphate) as a top-dressing can bring about valuable increases in yield. Reference can be found to this question in [2, 3, 12, 24, 25]. The effectiveness of nitrogen applies particularly in the areas of higher and more reliable rainfall. Where the rainfall is lower and less reliable the application of nitrogenous top-dressings must be approached with caution, except, of course, under irrigation.

Tobacco

Research in tobacco culture centres around the production of quality leaf suited to the markets, and the raising of yield per acre. Improvement in these is associated with variety, fertilizer practice, and curing methods. The papers by Brown [26, 27] are examples of contributions to the literature, in this connexion, whilst more recently the findings of the Kutsaga Station are made available to farmers through the bulletins and *Quarterly Review* of the Tobacco Research Board, and technical papers appear in the *Empire Journal of Experimental Agriculture*. Agronomically, two aspects of outstanding interest are the benefits of very early planting, if necessary with 'watering-in' of tobacco seedlings before the rains [66], and the inclusion of tobacco in a pastoral system, involving the planting of improved pastures which carry cattle for a period of years before the land is again ploughed for tobacco.

Wheat

The study of wheat growing under summer-rainfall conditions was recommenced [28] a few years ago, and reference to this and to irrigated wheat is to be found in the reports of various Stations [1]. The aim is to breed a rust-resistant wheat with a short stem. Whilst it is diffcult at present to produce 1,000 lb./acre of wheat under summer-rainfall conditions, yields of 3,000 lb./acre and upwards are obtained under irrigation in winter, in small areas. Agronomically, summer wheat is interesting because the best time of planting is mid-December, which is late for maize, and wheat would therefore be particularly useful in years where the commencement of the rains is late, and if a satisfactory variety for summer conditions can be bred, wheat would make an extremely useful addition to the regular crop range which at present is limited. Also, machinery exists for the complete mechanization of the wheat crop, whereas the satisfactory mechanical harvesting of maize under Rhodesian conditions has not yet been achieved, and the maize harvest is therefore vulnerable to labour shortages.

Cotton

This is a crop which has seen many vicissitudes, but would also be a useful addition to the regular crop range, if greater stability of production could be achieved. The lint can be absorbed by Rhodesian mills, whilst cotton-seed cake is readily consumed as an economical high-protein ingredient of livestock rations, of which the country is greatly in need. The essentials and problems of cotton-growing in Southern Rhodesia are broadly described in [29], whilst the recent situation in Nyasaland, where cotton is an important cash crop for the African farmer, is dealt with in [3]. Cotton is a warm-climate crop and does best at altitudes of 4,000 feet and below. Strains exist capable of producing a high yield in any area of suitable soil and climate in the Federation, but insect pests, notably the bollworms, *Diparopsis castanea* and *Heliothis armigera*, and the stainer bugs, *Dysdercus* spp., so frequently destroy the developing crop that farmers, both African and European, regard cotton-growing as hazardous. Modern insecticides, such as Endrin, DDT, and BHC,

are proving effective in control of these pests, and McKinstry [12, 30] refers to the study of their application at Gatooma and in the Sabi valley. If further work confirms the effectiveness of control, and if the application of these insecticides under various field conditions proves practical and satisfactory from the costs point of view, then a future for cotton as a regular crop in the farming system may well open up.

Potatoes

Potatoes are grown under natural rainfall conditions or with irrigation, particularly in the dry season. Seed was, until recently, mainly imported from overseas, but the development of seed production in the highlands of the eastern border of Southern Rhodesia is now taking place. The application of manure and fertilizers is reasonably well understood and, provided moisture is adequate, satisfactory yields can be expected. During the last few years, however, blight (*Phytophthora infestans*) has become a serious problem, and the attempt is now being made to secure a satisfactory resistant variety.

Groundnuts

Groundnuts are grown extensively by African farmers in small plots and to a large extent for their own consumption; they are not popular with European farmers because of practical difficulties experienced in planting, cleaning, and harvesting when growing them on a large field scale.

Sorghums

Sorghums, whilst considered suitable for the drier areas, have not made much headway, because of the lack of consumer demand and vulnerability to serious yield reduction through attack by birds.

Sugar-cane

This plantation crop has been cultivated for some years in the Sabi river valley, whilst more recently plantations have been established in the Zambesi river valley, at Chirundu, downstream from the Kariba Dam. Provided the application of irrigation waters and problems of soil fertility are efficiently managed, high yields of sugar-cane can be expected in the high temperatures of these low-lying valleys, so that national self-sufficiency in sugar production may come in time.

Maintenance of Fertility

It would certainly be advantageous if the crops discussed above could be fitted into a general rotation. Long rotations are useful for maintenance of soil fertility and control of insect pests and diseases. As mentioned above, the green-manure crop (e.g. sunnhemp, velvet bean, sunflower) has played an important role in Rhodesian farming, contributing, in particular, nitrogen and organic matter to the soil and improving its structure and friability, thus leading to easier handling [31]. The latter effect is partly brought about by timely ploughing, because the green manure is ploughed down in March–April when soil-moisture conditions are still favourable.

Rattray and Ellis [32] refer to the role of green manuring in maintaining soil fertility and remark that there is as yet nothing to rival it for efficiency in this connexion. However, the use of a green manure entails the total loss of revenue from the land to which it is planted in any particular season. The dividends accruing from it go to the succeeding maize crop. Present thought turns to the provision of the organic matter from other sources, viz. maize stalks and trash, or grass, the nitrogen being artificially applied in the form, for instance, of ammonium sulphate, before the maize stalks are ploughed in, to assist breakdown, or during the life of the grass. With grass there can be continuous production from the soil, through grazing animals, which also contribute fertility through dung and urine.

Animal Husbandry

The animal comes predominantly into the picture here. Rowland [33, 34] mentions this aspect. The integration of crops, animals, and pastures has become a most important trend of agricultural thought. The provision of winter forages, grass hay, legume hay, and silage has also received much attention in the battle to close the gap of the long dry period (April–October) when adequate grazing is not generally available to animals, except through the medium of irrigated pastures.

Tremendous progress has been made with the establishment of herds of cattle suited to the production of meat and dairy products in the Federation. Controversy centres round the suitability of indigenous and so-called exotic breeds, particularly in their relation to environment [11] in the various farming zones. Research in this complex sphere is of a very long-term nature, and the literature reveals very little concrete information. References pointing the way are [28, 39–42]. Elliot's work, started only a short while ago, is a particularly important development in the investigational line of progress. Progress with animals is closely linked with the development of farming systems suited to specific areas, and, in particular, the development of improved pastures.

Tsetsy fly. This fly, transmitting *trypanosomiasis*, still precludes development over wide areas and Chorley [57–60] and Whellan [61] describe this pest and the measures being taken to eradicate it. These measures include control of animals which act as carriers, and spraying, from the air, of the fly's breeding areas. The successful eradication of this pest would open considerable new areas to livestock production and the work is therefore of the greatest importance to the Federation.

Irrigation

Irrigation and water problems are referred to in various papers [1, 35–38, 54]. The artificial application of water to pastures opens up possibilities of feeding animals by quite different methods from those which have existed in the past. Only the future can show whether costs make these new methods economically feasible.

Erosion Control

The full understanding of the principles underlying the control of water and soil movement, in a country where the violence of precipita-

tion and the force of surface-water flow are so great, is of first importance. Studies of these problems are in progress [62] at various centres and are producing valuable information regarding agricultural practices leading to the control of surface water and thence erosion.

Mechanization

Agriculture in the Federation is becoming progressively more mechanized. Suitability of machinery to local conditions, possible adaptation of machines, and costs, need investigation, and research in these directions will doubtless develop as funds and facilities become available. The Federal Department of Conservation and Extension has organized a group of experts to carry out studies in this respect, whilst Gwebi College [28] has the nucleus of an institutional research centre in agricultural engineering.

Horticulture

This is a subject which has not received the attention it deserves although excellent basic work has been done, and the report of van der Merwe and de Wet [56] is of great interest where potentialities are concerned. Research, followed by practical developments, would provide possibilities of further advances in self-sufficiency of foodstuffs.

Farm Planning

Ten years ago MacKenzie [63] drew attention to the importance of 'farm planning'. Great progress has recently been made in this connexion, using aerial, soil, and vegetation surveys as the basis. Farm-planning teams are active in various areas, and the scope of the work is only limited by the number of trained staff that can be allocated to it. Its importance cannot be overestimated where correct land use and the development of the agricultural potential of the country is concerned.

Forestry

The country has considerable potential for the production of timber, particularly in areas of high rainfall. The Eucalypt has an important use in the production of 'hogs-heads', the containers in which tobacco is exported. Kelly-Edwards [64] refers to the birth of the Southern Rhodesia Forestry Commission.

Fish Culture

As mentioned above, the Federation has need of increased production of proteins for consumption by human beings and livestock. 'Fish farming' in the numerous dams now established on farms holds great potential in this connexion and important advances have been made. Maar [65] refers to Tilapia culture in farm dams.

Conclusion

The most important concept in the general trend of agricultural thought and research in the Federation is the departure from the 'row-crop' approach towards the inclusion of a grass ley in the farming system. Attention has been given to problems of management of the natural

veld [28, 43, 44], but during the last ten years 'improved pastures' have sprung into prominence. This entails the collection and propagation of species capable of responding to fertile conditions, and particularly the application of nitrogen, and of producing better grazing and higher yields of hay and silage than can be expected from the natural grasslands, even when well managed.

Tremendous progress has been made with this work in the last few years, and this is referred to in many of the references given below, notably [34, 45–53]. Linked with the work on grasses is the search for suitable legumes for inclusion in a seeded ley mixture. Clovers can be successfully established under irrigation and even under rainfall conditions in the highlands of the Eastern Districts. Generally speaking, however, the search for a legume suited to rain-grown conditions over most of the Federation has not yet met with success and provides one of the most important problems to be solved.

Although grasses which can be established only through the planting of roots are sometimes used, attention is now focused [55] on grasses capable of producing adequate quantities of viable seed and which make possible the establishment of seeded pastures.

The work of the last few years has made possible a substantial rise in yield levels of agricultural produce. The introduction of seeded, improved pastures to the farming system gives further hope of intensification, and of the possibility of making an adequate living from smaller units of land than was possible in the past.

Space has not allowed reference to all the work and publications which deserve mention. It is hoped, however, that reference to those papers listed below will lead to the easy discovery of others in the publications concerned.

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CORRIGENDUM

In the paper by V. A. Oyenuga in Volume XXV, p. 250, line 6 from bottom, for 12 weeks after sowing *substitute* 11 weeks after sowing and again 10 weeks later.